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THESIS

TESTING AND EVALUATION OF LOW-LIGHT SENSORS TO ENHANCE INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE (ISR) AND REAL-TIME SITUATIONAL AWARENESS

by

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March 2009

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13. ABSTRACT (maximum 200 words)

Video cameras have increased in usefulness specific to military applications over the course of the past four decades providing remotely controlled and viewed high-definition color images both at day and night conditions making them ideal for defense applications including force protection, critical asset monitoring, and perimeter surveillance. This is a result of many advances in technology including production of high-definition sensors, developing new video compression algorithms and IP capabilities, auto tracking features, image stabilization etc. Furthermore, the evolution of wireless networking technology and capability provides new practical options to gather Intelligence, Surveillance, and Reconnaissance (ISR) information.

The goal of this thesis is to test and evaluate performance and suitability of low-light cameras in a variety of operating environments and as a possible to more expensive infrared, thermal, or night vision applications. Understanding the true capabilities and limitations of the ALAN camera and its applicability to a wireless network by using an aerial vehicle will allow appropriate application and operation for military purposes.

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TESTING AND EVALUATION OF LOW-LIGHT SENSORS TO ENHANCE INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE (ISR) AND REAL-TIME SITUATIONAL AWARENESS

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ABSTRACT

Video cameras have increased in usefulness specific to military applications over the course of the past four decades providing remotely controlled and viewed high-definition color images both at day and night conditions making them ideal for defense applications including force protection, critical asset monitoring, and perimeter surveillance. This is a result of many advances in technology including production of high-definition sensors, developing new video compression algorithms and IP capabilities, auto tracking features, image stabilization etc. Furthermore, the evolution of wireless networking technology and capability provides new practical options to gather Intelligence, Surveillance, and Reconnaissance (ISR) information.

As part of Cooperative Operations and Applied Science and Technology Studies (COASTS) international field experimentation program, multiple cameras are being implemented and fused to provide persistent or near-persistent ISR. Cameras, including low-light versions, utilize both wired and wireless communication networks to deliver real-time video data for the use of decision makers.

The goal of this research is to test and evaluate performance and suitability of low-light cameras in a variety of operating environments as an option to more expensive infrared, thermal, or night vision applications. Ultimately, it will be clear whether the configuration of the Kestrel Technology Group (KTG) All Light / All Night (ALAN) camera is efficient for ISR missions depending on the test results. Understanding the true capabilities and limitations of the ALAN camera and its applicability to a wireless network by using an aerial vehicle will allow appropriate application and operation for military purposes.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternating current
ALAN	All light / all night
ATR	Automatic target recognition
C4ISR	Command and control, communications computers and intelligence, surveillance and reconnaissance
CAT 5	Categories 5
CCD	Charge-coupled device
CCTV	Closed-circuit television
CFA	Color filter array
CMYG	Cyan, magenta, yellow and green
CMOS	Complementary metal-oxide semiconductor
CO	Carbon monoxide
CO2	Carbon dioxide
COASTS	Cooperative operations and applied science and technology studies
COTS	Commercial-off-the-shelf
DC	Direct current
DHS	Department of Homeland Security
DoD	Department of Defense
DSC	Digital still camera
DSP	Digital signal processing
EO	Electro-optical
FAA	Federal Aviation Administration

FEX	Field experiment
FLIR	Forward-looking infrared
HTTPS	Hypertext transfer protocol secure
IEEE	Institute of Electrical and Electronic Engineer
IIR	Imaging infrared
IP	Internet protocol
IR	Infrared
ISR	Intelligence, surveillance, and reconnaissance
JPEG	Joint Photographic Experts Group
KTG	Kestrel Technology Group
LWIR	Longwave infrared
METOC	Meteorological and Oceanographic
MOE	Measures of effectiveness
MOP	Measures of performance
MPEG	Moving Picture Experts Group
MSO	Maritime Security Operations
MWIR	Mid-wave infrared
NPS	Naval Postgraduate School
NTSC	National Television Systems Committee
NVD	Night vision device
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
PAL	Phase alternating line

PTZ	Pan/tilt/zoom
QoS	Quality of service
RPV	Remotely piloted vehicles
R&D	Research and development
RGB	Red green blue
ROA	Region of awareness
ROI	Region of interest
SNMP	Simple Network Management Protocol
SWIR	Short-wave infrared
TCP/IP	Transmission control protocol/internet protocol
TOC	Tactical operation center
TNT FE	Tactical Network Topology Field Experiment
VAC	Volt AC
UAV	Unmanned aerial vehicles
WMD	Weapons of mass destruction

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I. INTRODUCTION

A. BACKGROUND

Video cameras have increased in usefulness specific to military applications over the course of the past four decades providing remotely controlled and viewed high-definition color images both at day and night conditions making them ideal for defense applications including force protection, critical asset monitoring, and perimeter surveillance. This is a result of many advances in technology including production of high-definition sensors, developing new video compression algorithms and IP capabilities, auto tracking features, image stabilization etc. Furthermore, the evolution of wireless networking technology and capability provides new practical options to gather Intelligence, Surveillance, and Reconnaissance (ISR) information. As part of the Cooperative Operations and Applied Science and Technology Studies (COASTS) international field experimentation program, multiple cameras are being implemented and fused to provide persistent or near-persistent ISR. Cameras, including low-light versions, utilize both wired and wireless communication networks to deliver real-time video data for the use of decision makers.

The goal of this thesis is to test and evaluate performance and suitability of low-light cameras in a variety of operating environments as an option to more expensive infrared, thermal, or night vision applications. Ultimately, it will be clear whether the configuration of the Kestrel Technology Group (KTG) All Light / All Night (ALAN) camera is efficient for ISR missions depending on the test results. Understanding the true capabilities and limitations of the ALAN camera and its applicability to a wireless network by using an aerial vehicle will allow appropriate application and operation for military purposes.

B. SCOPE OF THE THESIS

The scope of this thesis will focus on testing and evaluation of the KTG ALAN camera. The primary objective is to determine the performance of a KTG ALAN camera at night and other low light / reduced visibility conditions. To accomplish this objective, several tests and an evaluation plan will be drafted and executed.

C. RESEARCH QUESTIONS

Primary Question:

- Can KTG ALAN cameras provide real-time situational awareness in a tactical environment under varying operational environments and meteorological conditions?

Secondary Questions:

- Examine the performance of the KTG ALAN camera in different meteorological and environmental conditions.
- What are the possible surveillance applications that KTG ALAN camera can be used within?
- What is the minimum light level KTG ALAN camera can be used for color operation?
- What are the advantages and disadvantages of different imaging sensors used for ISR?
- What are the recent technologies on surveillance platforms, aerial and IP-surveillance?

D. METHODOLOGY

The research will be conducted in three phases and consist of an analysis of the KTG ALAN camera technology, required wireless technology through literature reviews and tests.

Phase 1: Literature review.

This phase will include the necessary academic review of existing technical material for ISR, sensors and type of cameras. Additionally the research will focus on the required attributes depending on the use of the KTG ALAN camera.

Phase 2: Test of the system, data collection.

Measures of Performance and Measures of Effectiveness (MOP/MOE) will be created. The MOP/MOE will be used to develop a test and evaluation plan and provide a group of parameters for the evaluation of the system. Once a test plan is developed, the airborne testing of the KTG ALAN camera will be executed. The system will be tested in various environments mostly depending on the schedule of COASTS international field experimentation program.

Phase 3: Analysis of results, conclusions and documentation.

First part of the final phase consists of analyzing the results of each test. The results will be compared to the determined MOP and MOE. After analyzing the results from the tests, it will be possible to determine the effectiveness of the airborne KTG ALAN cameras in real-world military environments, make conclusions and suggest the possible utilization areas which KTG ALAN cameras can function properly.

E. BENEFITS OF THE STUDY

- Better understand the capabilities and limitations of existing KTG ALAN camera technology in operational environments.
- An effective use of all-light cameras provides continuous situational awareness in tactical environments. In addition, color operation offers another dimension to target or situational awareness discrimination.
- Increase the capabilities of gathering intelligence, surveillance and reconnaissance information during low-light times.
- Using an aerial vehicle may allow us have longer ranges due to the fact that not looking through a large depth of ground haze.
- Understand the efficiency and the applicability of KTG ALAN camera for border surveillance.
- Contribution to the COASTS field experimentation program.

F. THESIS OUTLINE

Chapter I provides an overview and general outline of the work.

Chapter II contains the essential background information about intelligence, surveillance and reconnaissance. This information includes the recent technologies on surveillance platforms, aerial and IP-surveillance as well. Additionally, the COASTS field experimentation program is briefly overviewed.

Chapter III consists of the general information about design and analysis of imaging systems and the typical electro-optical (EO) and imaging infrared (IIR) scenarios. In addition, the components of an imaging system analysis are explained.

Chapter IV provides the information about the types of cameras depending on their imaging system. In addition, their applications on different areas are explained.

Chapter V includes the test and evaluation planning, selected metrics and MOE/MOP for ALAN camera testing. Then, an introduction and a description of KTG ALAN camera and other required equipment is provided. Moreover, chapter V presents information related to the tests and their results in addition to the feasibility and applicability of KTG ALAN camera as an ISR source.

Lastly, Chapter VI provides the conclusions and recommendations reached concerning the study.

II. INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE (ISR)

A. OVERVIEW OF ISR

Throughout history the diverse nature of U.S. border defense has been challenged by an equally diverse array of threats ranging from terrorists to drug smugglers, arms dealers, and human traffickers, but it must be admitted that 9/11 was both a wake-up call to America and the other countries to be more vigilant in intelligence, surveillance and reconnaissance. The twin terror attacks of 9/11 were a direct assault on our world open borders, free trade, and the expanding zone of global economic integration [1].

Similarly Turkey suffers several serious Homeland Defense issues. The success of National Security in Turkey is highly tied to the

- Prevention of terrorist attacks
- Protection of Nation's resources and citizens
- Measures against border infringement, illegal immigration and other acts of or natural disasters [2].

In June 2004, the terrorist organization PKK finished the so-called ceasefire, which started on February 1999 when the leader of the organization, Abdullah Ocalan, was captured in the Embassy of Greece in Kenya while carrying a Greek Cypriot passport [3].

After the PKK, a Marxist-Leninist separatist organization and formally named the Kurdistan Workers Party, in an attempt to damage Turkey′s tourist industry, bombed tourist sites and hotels, kidnapped foreign tourists and killed Turkish Government security forces, local Turkish officials and villagers who oppose the organization within Turkey [4].

In the meantime, the Iraq War seriously aggravated the illegal immigration problem in Turkey. In this honorable fight with terrorism and illegal immigration, Turkey requires more secure borders.

The borders of a country can be conceptualized as four segments, or points of entry. Three segments—airports, ports, and guarded land points—are official. The fourth—unguarded land borders and shoreline—is unofficial and is used primarily by migrants, smugglers, traffickers, and perhaps terrorists. Each segment is to some degree porous, because of the volume of activity and the amount of physical space that must be protected. Physical space is particularly important at unofficial points of entry [5].

All segments are monitored and protected by border patrol agents, video cameras, ground sensors, physical barriers, land vehicles and manned aircraft in the U.S. But past difficulties in securing the borders in conjunction with fears that terrorists could exploit existing security vulnerabilities by surreptitiously crossing the borders has prompted Congress to call on the Department of Homeland Security (DHS) to examine the potential use of Unmanned Aerial Vehicles (UAVs) [6].

Since 9/11, as the U.S. has decided to tighten up its border security, it has been pulled in two distinct and paradoxically irreconcilable directions:

- Withdraw inward with new layers of security protection, surveillance and detection.
- March outward into the world and all its dangers, to prevent and pre-empt terror at its very source [7].

As we enter the seventh year after 9/11, it is becoming increasingly clear that securing the homeland is expensive and potentially endless. It is also clear that simply erecting electronic barriers and enhancing perimeter defenses with the latest generation of biometric sensors, motion detectors and infrared (IR) scanners, along with biological, chemical, and nuclear detection would still leave the nation which has such long and permeable borders vulnerable to a variety of external threats. This is coupled with the virtue of the U.S. continental scale, a vast and dispersed infrastructure, and economic dependence on the free movement of trade goods through seaports, land border crossings and airports. America remains frustratingly vulnerable to future mass terror attacks, presenting would-be terrorist with a long list of potential soft targets that are virtually impossible to secure.

Modern terrorist groups may try to leverage the isolated and rogue states who wield unconventional weapons such as radiological bombs, chemical and biological weapons, and improvised weapons of mass destruction (WMD) such as the commandeered commercial jumbo jets used on 9/11. Consequently all nation-states have been compelled to enhance their border surveillance with a mix of new and conventional surveillance technologies, enabling them to see further and clearer than ever before.

The deployment of ground and sea-based surveillance systems in conjunction with aerial and space-based systems that include both the popular unmanned aerial vehicles as well as orbiting satellite reconnaissance systems is accepted as the best practice to provide early warning and detection [8].

1. Short & Medium Range Surveillance Platforms

Small, lightweight, and consistent radar systems are being used successfully and for many years within most, if not all, modern military organizations. With the help of recent advances in both technology and signal processing techniques, wider ranges of products are being manufactured in military and civil markets [9].

An ordinary border security system may be composed of several platforms, which provides short-range, medium-range and long-range surveillance. Examples of the short and medium-range platforms are:

- Perimeter fences are an electronic surveillance technology for intrusion detection and warning. Ground-based they provide short-range coverage up to around 500 meters.
- Observation towers enhance surveillance capability many tens of kilometers away from an installation. Ground-based they provide medium-range surveillance.
- Mobile ground observation platforms include land vehicles as well as maritime vessels. These surveillance platforms typically patrol frontier regions and coastal waters, enhancing the reach of medium-range surveillance sensors through their mobility.
- Observation aerostats are stable platforms, generally tethered balloons, which allow for extended observation over wider areas, enhancing the reach of surveillance sensors beyond what can be seen from an observation tower [7].

Figure 1. Zeplin as an Example of Observation Aerostats

For example, the South Korean army uses up-to-date robots, the Intelligent Surveillance and Guard Robot developed by Samsung Techwin, as multi-functional security guards to protect the borders of their country. Main features of these exceptional soldiers are tracking, firing and voice recognition capabilities.

Figure 2. Intelligent Surveillance and Guard Robot (From [10])

In addition to protecting borders, short-range surveillance and perimeter detection systems are used for securing sensitive and high value installations.

Short and medium-range platforms utilize a wide variety of sensors including systems such as taut-wire perimeter detection, vibration intrusion detection, electromagnetic intrusion detection, electrostatic field disturbance, electro-optical observation, and microwave field disturbance detectors. For high-resolution imaging, motion detection, temperature-differentiation and night-vision, there are a variety of electro-optical (EO) imaging sensors that can be used. Examples include optical video detection systems, using arrays of commercially available closed-circuit television (CCTV) cameras well-suited for daytime surveillance; IR detection systems, that can measure changes in thermal energy and provide night-surveillance; and laser illumination systems that can illuminate targets, and enable higher-resolution imaging when combined with other EO sensors. Additional optical components include computer-operated pan/tilt/zoom (PTZ) cameras, visible or near-infrared illuminators for night vision with conventional cameras; and image intensifiers for long-range night vision with conventional cameras [7].

Over wide-perimeter areas laser illuminated viewing and ranging techniques can enhance long-range surveillance, and can detect threats over ten miles away. Since laser-illumination does not use microwaves the reflected signal is easily monitored as a digital video image. This technology provides next-generation surveillance systems to produce real-time, high-resolution imagery for threat clarification at wider areas and longer ranges than the present possibility. Layers of the previously mentioned surveillance platforms can be used to enhance border security. Surveillance sensors are used on ground systems, attached to towers and fences; on ground vehicles and on ships; on stationary aerostats and on automated unmanned aerial vehicles which can provide persistent surveillance of wide areas and on satellites [8].

These platforms can provide clear, highly detailed imagery that is critical in challenging coastal and urban environments. Applications can provide better standards on national security, intelligence, surveillance, reconnaissance, search and rescue, border patrol, coastal patrol, unmanned aerial vehicles and navigation.

2. Long-Range Border Surveillance

High-altitude mobile observation platforms provide long-range mobile surveillance from the sky via airplanes, helicopters, and satellites. Their high-altitude enables wide-area surveillance.

Long-range platforms use a similar mix of EO sensors enabling optical and thermal imaging other than radar. This enables all-weather surveillance, as seen during the sandstorms in the opening days of Operation Iraqi Freedom when satellite and aerial surveillance platforms allowed for all-weather targeting of Iraqi positions [8].

Figure 3. The RQ-4 Global Hawk is an UAV Used by The US Air Force as Surveillance Aircraft

3. Data Management

There are two common approaches of sensor data management: data fusion, and sensor fusion. Data fusion may be defined as the approach of transferring data from radar, acoustic, thermal, and EO imaging to a central management software system that analyzes the data and then presents it in such a way to ease decision-making. For instance, this enables a decision-maker to view fused radar and EO images. Using EO provides a decision-maker with a good representation of the scenario, but poor concept of the movement. Conversely, using radar, a decision-maker gets a bad image, but a very good comprehension of movement about changes. Thus, analyzing both together, a decision-maker gets an excellent image with an emphasis on which aspects are changing.

The second common approach is sensor fusion. This provides the decision-maker the ability to accumulate and combine data together to compare the images and to distill useful information. By integrating the data from multiple sensors, it is feasible to have the benefits of IR and other sensors on the same image, and thus the commander can make better decisions. Most ground stations contain a variety of displays for the different sensors, one for visible, one for IR, and one for radar, which may require much effort to monitor. But, once all sensor outputs are placed on the same display, it yields a lot of advantages.

B. COOPERATIVE OPERATIONS AND APPLIED SCIENCE & TECHNOLOGY STUDIES

1. COASTS Overview

The Naval Postgraduate School (NPS) Cooperative Operations and Applied Science & Technology Studies (COASTS) international field experimentation program is a combined Research and Development (R&D) effort exploring the use and application of Commercial-off-the-shelf (COTS) Command and Control, Communications Computers and Intelligence, Surveillance and Reconnaissance (C4ISR) technologies for multi-national, cooperative use within tactical and operational situations. There is an increasing and immediate requirement for low-cost, state-of-the-art, real-time, mobile threat warning and tactical communication equipment that can be rapidly deployed, scalable, and formed around operational needs and considerations.

The COASTS field experimentation program consists of U.S. and international partners. Figure 4 provides an overview of the organizational relationships. Within this organization, NPS faculty and students provide overall leadership and management of COASTS with support provided by Office of Naval Research (ONR) Reservists. The Office of the Secretary of Defense (OSD) and the Department of Homeland Security

(DHS) and their agencies provides funding and requirements. The commands and agencies provide COASTS operational guidance, sponsorship and in some cases direct participation in the experiment.

In addition, COASTS is coordinated with the U.S. Department of State and the some overseas the Department of Defense (DoD) organizations. Since international partnerships are key to the success of COASTS, and several foreign government commands and agencies are included. The final major organizational components are commercial vendors that provide the technologies and expertise upon which the COASTS architecture is built.

Figure 4. COASTS Overview and Organizational Relationships

COASTS comprises a series of field experiments (FEX) spanning each fiscal year, with the capstone field experiment conducted annually in Thailand in May and June. COASTS iterate annually and build on the successes and lessons learned from the previous capstone field experiments. A system-of-systems C4ISR architecture which can be rapidly deployed into a harsh environment with limited logistics support and is designed to test candidate technologies in the context of a modern warfare scenario is the COASTS test bed deployed to these field experiments.

The COASTS program provides a flexible test bed environment for the assessment of new systems and technologies. By providing this technology test bed and critical assessment of participant technologies, COASTS thus allows for limited pre-acquisition program assessment and evaluation of these technologies in the context of multiple mission scenarios as well as combined and interagency force missions. These include maritime security and interdiction operations, force protection, tactical surveillance and reconnaissance, counter-terrorism and transnational crime, counter-proliferation of weapons of mass destruction (WMD), information operations, and civil affairs.

2. COASTS Objectives

The high-level technical objectives for COASTS-07 are as follows:

- Make ISR data and information visible, available and usable when and where needed.
- Improve capabilities of Maritime Security Operations (MSO) through technology development in MDA, force protection, and command and control.
- Investigate deployment issues surrounding hastily formed networks in rugged and varied terrain under adverse climatic conditions.
- Investigate the utility of mini-UAVs and sensor suites in rainforest, littoral, and maritime environments.
- Demonstrate ship-to-ship and ship-to-shore communication capabilities in deployable form factors.
- Investigate net-centric information management in a multi-national environment across tactical, operational, and strategic domains.
- Investigate the dissemination, sharing, and security of information between various U.S., international, and commercial partners [11].

3. COASTS Technologies

COASTS goals include the introduction of new technologies such as recent advances in wireless networking and biometric data gathering, improved C4ISR sensors and the new UAV capabilities. The operational goals are to provide training and support refinement for combined and interagency forces conducting several principal missions: force protection, tactical surveillance and reconnaissance, internal defense, combating terrorism and transnational crime, civil affairs, counter-proliferation of weapons of mass destruction, information operations, maritime security, and maritime interdiction operations.

The phased spiral development that previously proved successful is practiced during COASTS FEXs. Initial phases are limited to reduced-scale baseline deployable architectures designed and tested in U.S. locations. Follow-on phases are to provide customized benchmarking and an option to optimize system performance in the much more challenging international environments. Finally, the complete COASTS system architecture is deployed and operational demonstrations are conducted. This approach reduces technical risk by verifying that the new technologies can be configured and integrated to function in the intended environments.

The COASTS principal technologies, which are intended for use by individual and small units and are network-based include:

- Wireless network communications systems
- Simple Network Management Protocol (SNMP) based multi-sensor networking devices
- Networked sensors
- Biometric systems
- UAVs (fixed and rotary wing)
- Tethered balloons
- Portable computing systems
- C4ISR software applications
- Deployable meteorological and oceanographic (METOC) sensor suites
- Information management portals [12]

C. AERIAL-SURVEILLANCE USING VIDEO CAMERAS

There is developing focus on usage of video cameras in performing aerial surveillance. In comparison with the obsolete version framing cameras, videos provide the ability to monitor ongoing activity within a scene and to automatically control the camera to track the movements.

Aerial surveillance is not new. Besides various military applications for observing enemy activities, aerial surveillance also has many commercial applications for monitoring resources such as forests and crops. Similar imaging methods are used in aerial information collection and search and rescue. Aerial imagery was used for topographic mapping in 1849 by Colonel Aime Laussedat of the French Army Corps of Engineers. Kites and balloons were used in order to fly the cameras. In 1913, airplanes were flown to obtain photographs for mapping goals. Aerial images were used extensively in World War I, primarily in reconnaissance and intelligence [13].

Recently, aerial surveillance has been performed using film or electronic framing cameras. The objective was to collect high-resolution images of an area under surveillance that could then be tested by analysts to extract information of concern. Nowadays, there is extensive focus on using video cameras for such tasks. Video captures dynamic events that cannot be realized from aerial still images. It provides feedback and triggering of actions based on dynamic events and enables important and timely intelligence and understanding that is not otherwise available. Video observations can be used in order to detect and geo-locate moving objects in real time and to control the camera, for example, to follow detected vehicles or constantly monitor a site. However, video also brings new technical difficulties. Video cameras have lower resolution and worse quality than framing cameras. To get the resolution required to identify objects on the ground, it is generally necessary to use a telephoto lens, with a narrow field of view. This leads to the most serious shortcoming of using video in surveillance. It provides only a soda straw view of the scene.

The camera has to be scanned to cover extended regions of interest. An observer watching the screen must pay constant attention, as objects of interest move rapidly in and out of the camera field of view. Video can also lack a larger visual context. The observer has difficulty perceiving the relative locations of objects seen at one point in time to objects seen moments before.

A camera operator can have difficulty manually controlling the camera to scan a scene or to hold an object of interest in view because of the soda straw view of the world provided by video. Video contains much more data than old version surveillance imagery, so it is expensive to keep. Once stored in a database, surveillance video is difficult and tiresome to search during analysis.

To be able to use video in aerial surveillance, new video technologies were developed that make it much ergonomic for human operators to use and interpret video data. Technologies developed a self-control for cameras and provided them the capability of detect and geo-locate objects of interest. New techniques exist to interpret and present video imagery to humans to provide an immediate, in-depth understanding of the observed scene. Technologies also made it feasible to compress and store easily and to give users easy access to archived surveillance videos.

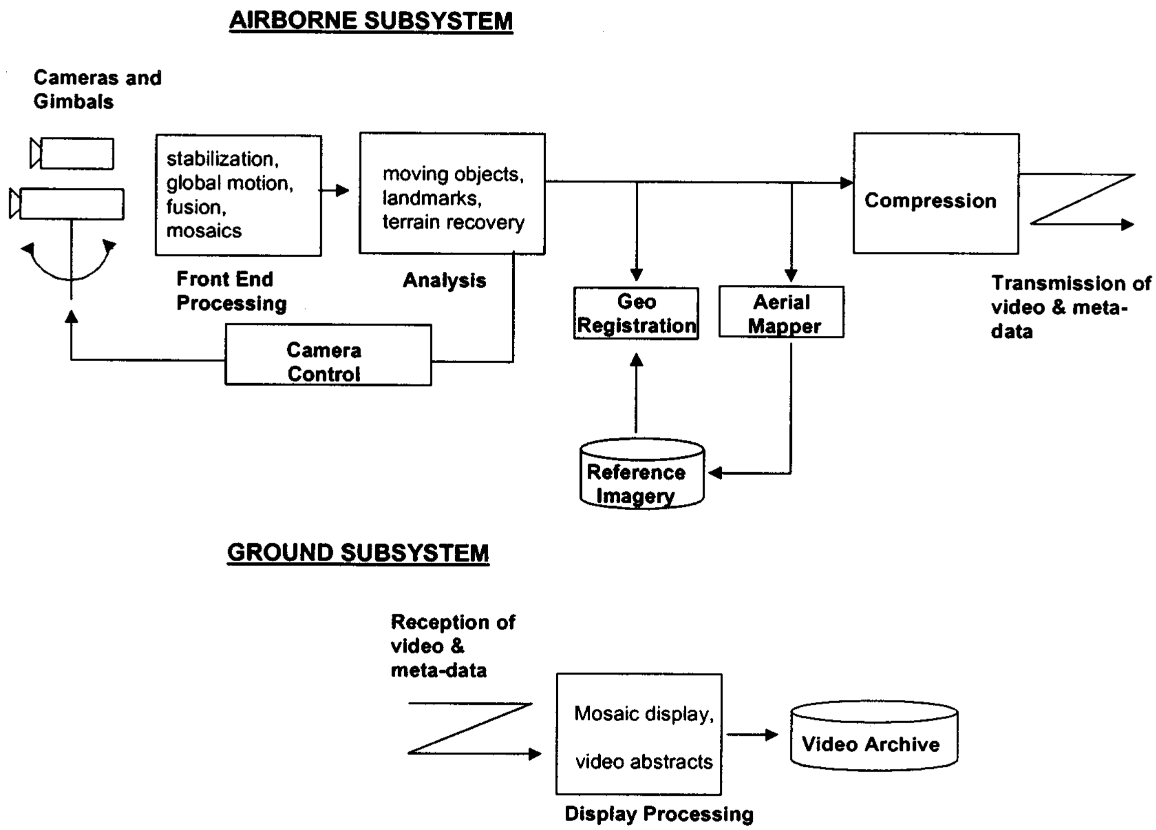

Figure 5. Components of an example aerial video surveillance system for use with an unmanned aerial vehicle. Surveillance systems for other military and civilian applications would generally use a subset of these components (From [13])

According to the example aerial video surveillance system shown above, the locations of moving objects can be detected on a mosaic display. As they change their locations, their tracks can be represented symbolically as a sequence of lines or dots, or as images of the moving object itself put in at ordinary time intervals, as shown in Figure 6. This provides the observer with a plot of extended scene activities that can be interpreted in a rapid way.

Figure 6. Tracking a White Vehicle Using The Model (From [13])

D. IP-SURVEILLANCE

Internet Protocol (IP) is the most general protocol for communication over computer networks and the Internet. An IP-Surveillance application produces digitized video streams that are transferred via a wired or wireless IP network, enabling monitoring and video storing as far away as the network reaches, as well as enabling integration with other kinds of systems such as access control.

According to industry analyst, J.P. Freeman and Co., Inc. there is at least 20 million analog cameras installed in the U.S. alone. Of this 20 million, 1.5 million analog cameras were sold in 2002. Despite these rather significant numbers for analog cameras, it is networked cameras that have emerged as the fastest growing product category, providing a clear indicator that IP-based systems are poised to take over [14].

Network cameras are connected directly to an IP-based network and used together with the applications on the network, enabling users to have cameras at remote locations and view, store and analyze live video at another location, or multiple locations, over the network and internet.

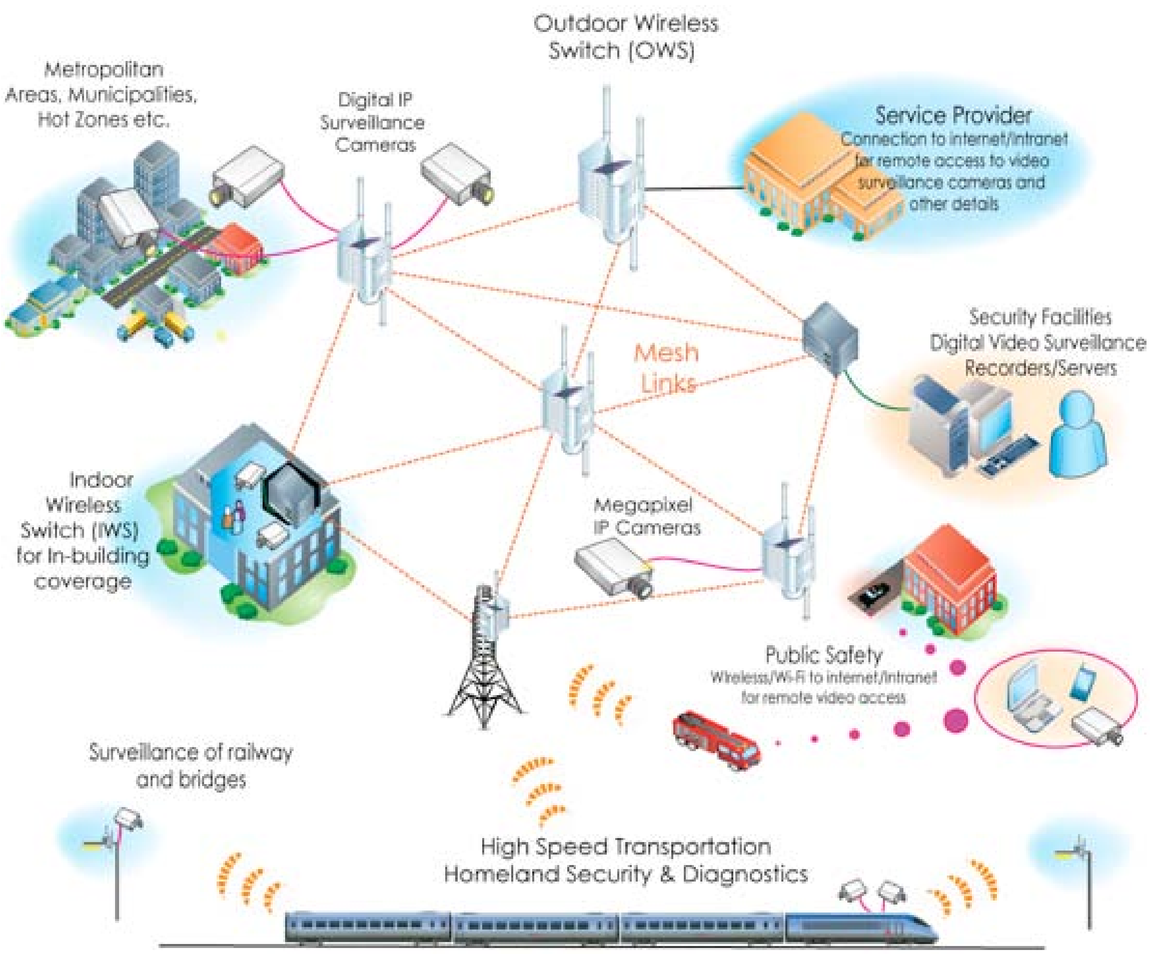

Figure 7. A Sample Wireless Mesh Distributed Digital Video Surveillance (From [15])

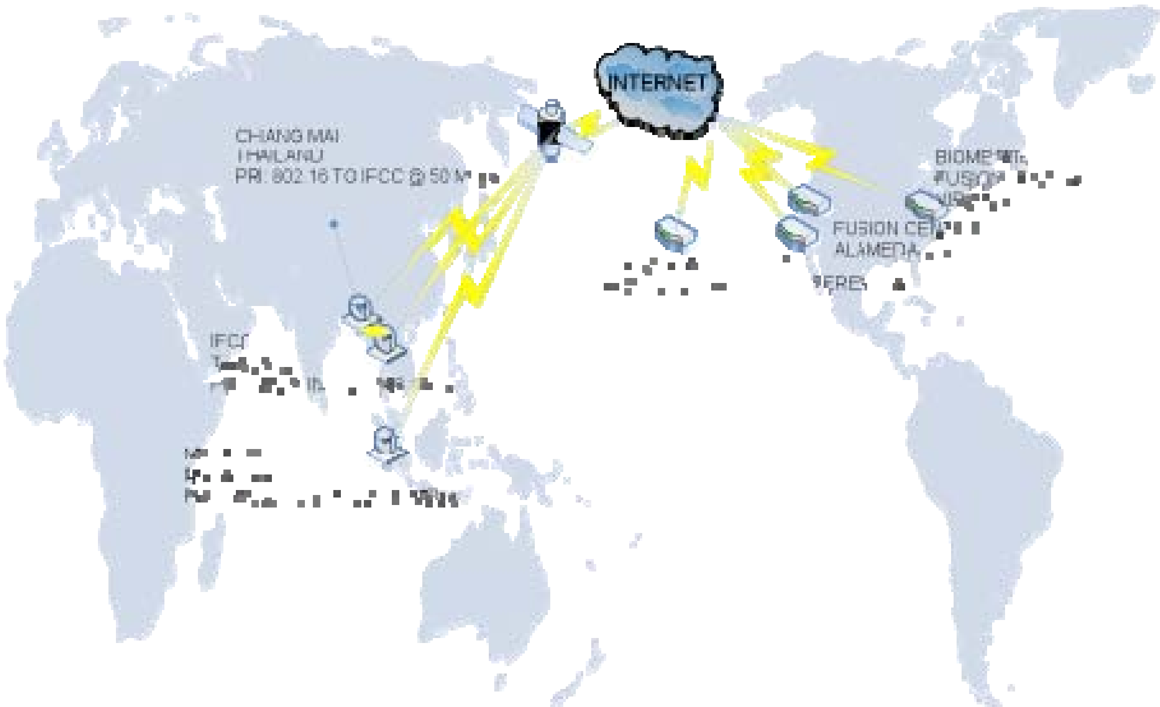

Figure 8. Wide Area Network for COASTS 2007 (From [11])

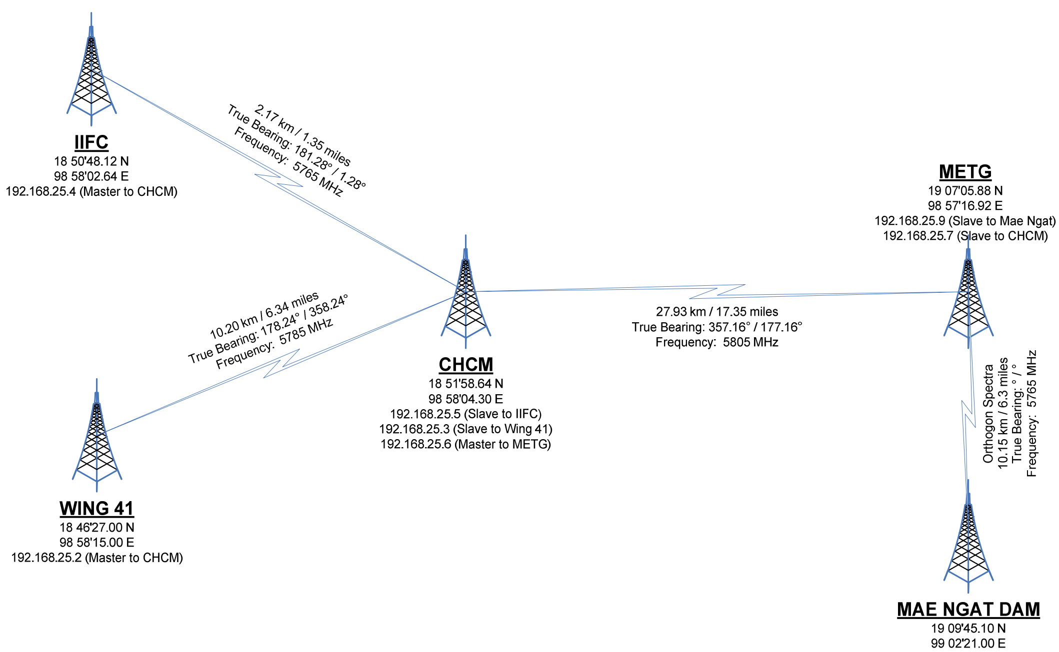

Figure 9. WiMax / Terrestrial Back Haul Links for COASTS 2007 (From [11])

Whether it is digital network cameras or analog cameras connected to video servers or an installation that uses both camera types, IP-Surveillance is proving to be attractive in nearly all markets. In several applications this revolutionary innovation is changing traditional systems to low costs and increase safety. While in other applications, it is being used for the first time to create and stimulate new, exciting markets.

Figure 10. Axis 213 PTZ IP Camera

Because of its measurability, among other benefits, IP-Surveillance is an established, good-looking technology not only for enhancing or developing existing surveillance and remote monitoring applications, but also for a numerous new applications in vertical markets as well including,

- Education: security and remote monitoring of school playground areas, corridors, halls and classrooms, as well as security of the buildings themselves.
- Transportation: remote monitoring of railway stations and tracks, highways and airports
- Banking: traditional security applications in high street banks, branch offices and anywhere ATMs are located
- Government: within security surveillance applications, often integrated into existing and new access control systems
- Retail: for security and remote monitoring purposes to making store management easier and more efficient

- Industry: monitoring manufacturing processes, logistic systems, warehouse and stock control systems
- Police: monitoring potential areas to reduce crime rates
- Municipality: city planning, traffic management [14]

1. Advantages of IP-Surveillance

Some of the most common advantages of IP-based video surveillance are mentioned below:

- Scalability: IP-Surveillance offers any frame rate for any camera at any time without restrictions. IP-Surveillance scales from one to thousands of cameras in increments of a single camera.
- More cost efficient infrastructure: Most facilities are already wired with twisted pair infrastructure, so with IP-Surveillance no additional wiring is required. Only one type of network (IP) connects and manages the enterprise for data, video, voice, and others. It makes management more effective and cost efficient.
- Remote accessibility: Any live or recorded video stream can be securely accessed and controlled from any location in the world over wired or wireless networks.
- Intelligence at camera level: Motion detection, event handling, sensor input, relay output, time and date, and other built-in capabilities allow the camera to make intelligent decisions on when to send alarms and to whom, when to send video, and even at what frame rate or resolution to send the video.
- Lower system cost: The IP-Surveillance system has provided to be a lower cost option for many installations. Open and standard network, server and storage equipment enables competition between choices [14].

III. DESIGN AND ANALYSIS OF IMAGING SYSTEMS

A. GENERAL

There are various types of imaging systems due to the different techniques that may be utilized for imaging. Types of imaging systems may vary depending on the technique as well as the purpose or the electronics involved. For the purposes of this study, the focus will be on imaging infrared systems (abbreviated as either IIR or I^2R) and electro-optical (EO) systems.

IIR systems are also denoted as forward-looking infrared (FLIR) systems. A FLIR pod on an F-16 aircraft is shown in Figure 11 below.

Figure 11. FLIR Pod on An F-16 Aircraft (From [16])

IIR or FLIR systems operate either in mid-wave infrared (MWIR) or in long-wave infrared (LWIR) and respond primarily to light emitted by objects in the scene [17]. On the other hand, the EO systems respond to wavelengths within the 0.4 – 0.2 μm region, which also includes the visible and short wave infrared (SWIR) bands.

B. TYPICAL SCENARIOS FOR MILITARY APPLICATIONS

There are mainly two military application scenarios associated with the above-mentioned imaging systems. A typical EO scenario and a typical IIR-FLIR scenario will be considered.

1. Typical EO Scenario

As mentioned above, EO systems utilize the 0.4 – 0.2 μm band. Since the human eye is also responsive to some part of the band, the EO systems provided imagery is familiar to human vision. Targets, backgrounds and noise have reflectivity dependent properties in the EO wavelengths. External radiation or illumination is provided by the sun, the moon and the stars or by artificial lighting [17]. A typical EO scenario is shown in Figure 12 below:

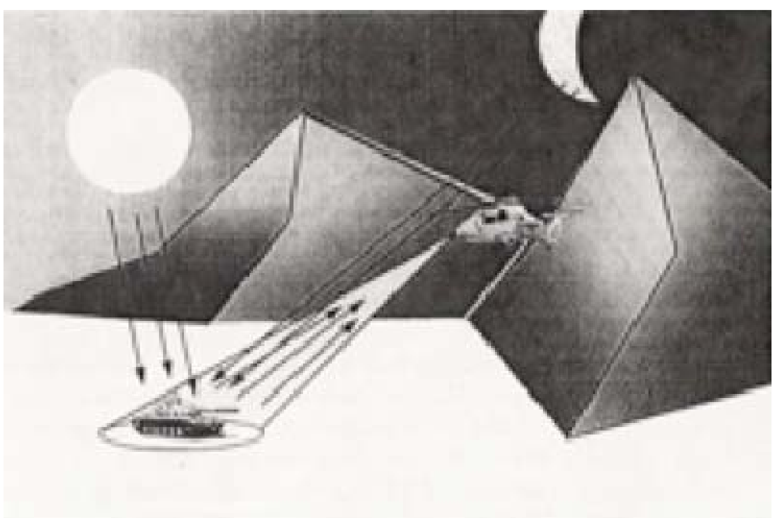

Figure 12. Typical EO Scenario (From [17])

Reflectivity of the target and background affects the performance most in this scenario. Reflectivity of the surfaces is strong parameters of the wavelength. While the targets and the backgrounds reflect the light, the light is also scattered through atmospheric, aerosol, smog or smoke particles [17].

The output of the sensors in this scenario may not always be eligible for human eye perception and interpretation. In such cases the output of the EO sensor systems goes through the automatic target recognition (ATR) process. Several signal and image processing techniques may be employed for these cases for detection, recognition, identification and classification.

2. Typical IIR Scenario

IIR scenario is applied for the cases of visualization of targets under night or poor lighting conditions. So this scenario is closely related to night vision devices (NVDs). A typical IIR system might be employed for battlefield night vision, unlit area surveillance, and fire detection within smoke filled naval assets [17]. A typical IIR scenario is illustrated in Figure 13 below.

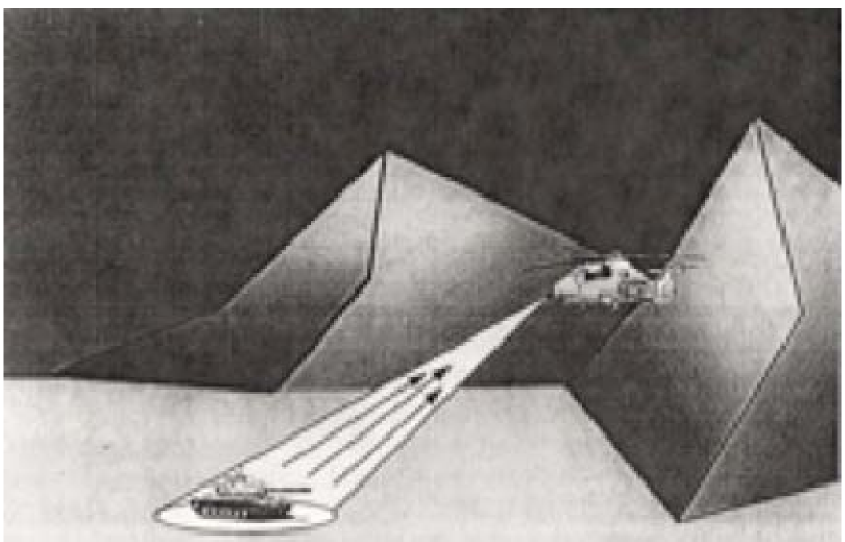

Figure 13. Typical IIR Scenario (From [17])

There are two primary transmission windows within the electro-magnetic (EM) spectrum for IIR systems, which are the MWIR (3 – 5 μm band) and the LWIR (8 – 14

μm band) regions. The other regions within the IR band are not suitable for IIR transmissions due to higher atmospheric absorption that makes long-distance imaging nearly impossible [17].

For the sake of terminological consistency, the common tendency is to use the term IIR for these systems while for military systems the term FLIR is widely employed.

C. ANALYTICAL PARAMETERS

Design and analysis of imaging systems are done via various parameters. The common point of these parameters is their spectral dependence. In other words most of these parameters are strong functions of the wavelength. This dependence is mainly the consequence of various factors including [17]:

(1) Scene's characteristics

(2) Atmospheric degradation

(3) Individual response of the sensor's components

The above is not a thorough list of parameters including those necessary so as to analyze and evaluate an imaging system. A more general list is presented in Table 1.

Analytical parameters	
Illumination	**Sensor detector**
Spectral irradiance	Responsivity
	Detectivity
Target	Noise characteristics
Reflectivity	Detector angular subtense
Emissivity	
Size and spatial characteristics	**Sensor electronics**
Temperature	Temporal characteristics
	Digital or analog filter characteristics
Atmosphere	
Weather conditions	
Obscurants	**Display**
Transmission	Resolution
Optical transfer function	Brightness and contrast
Scattering	
	Human psychophysics
Sensor optics	Temporal response
Lens transmissions	Image transfer function
Mirror reflectivity	Brightness dependence
Filter transmission	
Aberrations	**ATR or AiTR response**
Diffraction	Discrimination probability
Aperture size and shape	False-alarm rate

Table 1. Analytical Parameters of an Imaging System (From [17])

Among the parameters given in Table 1, sensitivity and spatial resolution are the two key parameters to the performance evaluation of EO and IIR sensors [17].

Sensitivity of a system may be generally defined as the noise level present at the target background when target detection is still possible. Thus, the two important parameters so as to measure the sensitivity of any system are the signal level at the sensor from the target and the noise level from the target background. Sensitivity of the sensor systems plays a dramatic role when the application includes detection of targets with relatively low emitted signal power under relatively high noise levels within the application environment.

Intelligent decisions in terms of target detection, recognition, identification and classification can be made using sensor systems with relatively high sensitivities [17].

Spatial resolution may be defined as "the ability to distinguish between two closely spaced objects on an image". As it is frequently misinterpreted spatial resolution is "not the size of the smallest object that can be seen" [18].

Actually spatial resolution is a conflicting parameter with sensitivity in most cases. So, trade offs in terms of design parameters so as to optimize spatial resolution and sensitivity might be required. For example, if the design is executed for a certain optical diameter an increase in sensor’s focal length may increase spatial resolution while the trade off is decreased sensitivity [17].

D. COMPONENTS OF AN IMAGING SYSTEM ANALYSIS

The analysis of an imaging system, either EO or IIR, requires the analysis of various parameters associated with the three main components of the system: radiation sources (targets and backgrounds), the atmosphere and the sensor system itself [17]. This approach is presented in Figure 14 below.

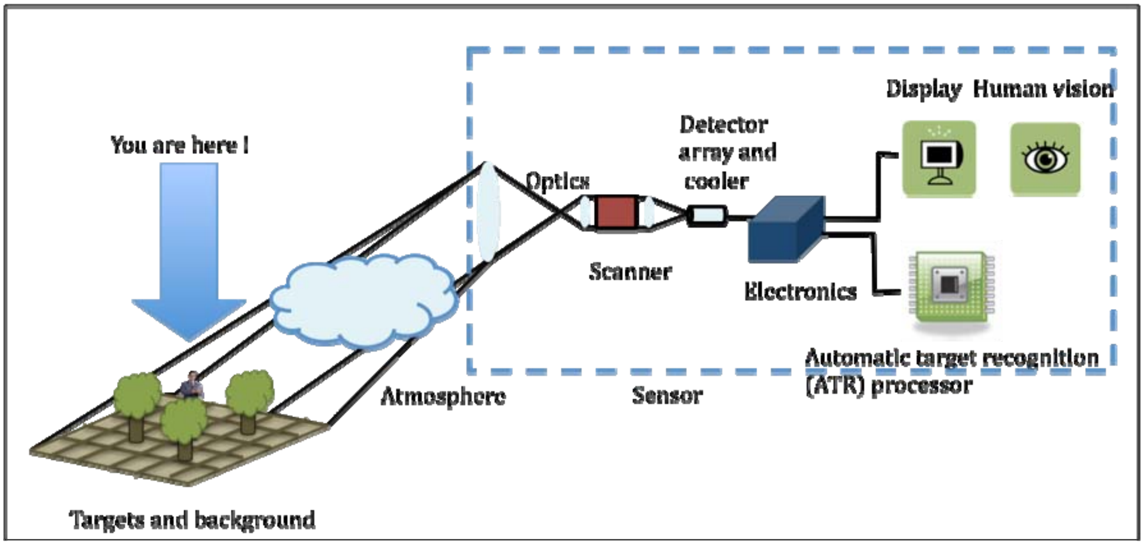

Figure 14. Block Diagram of a Generic EO or IIR Imaging System (From [17])

The block diagram in Figure 14 serves as a component roadmap to the analysis of the imaging system.

1. Sources of Radiation

Sources of radiation include objects on the imaging scene which are the targets and the backgrounds. Analysis of these radiation sources requires radiometric and photometric measurements and sensitivity considerations.

2. Atmosphere

Scattering and absorption are the two primary phenomena effecting atmospheric radiation. Both scattering and absorption are strongly dependent on the wavelength. Absorption occurs when certain types of particles interact with radiation from the target and the background (e.g. the radiation sources.). Water vapor, carbon dioxide (CO_2), ozone and carbon monoxide (CO) are some examples of efficient absorbers within the atmosphere. Scattering might be defined as the redirection of the targets radiation from the particles in the air [17].

3. Sensor System

The sensor includes optics, scanners, detectors, electronics, display, and human perception. If ATR processing is utilized then human perception may not be required. The effect of optics over the imaging system performance may be expressed by the diffraction effects associated with the optics, the geometric blur caused by imperfect imaging lenses, and the signal amount collected by the optics. The detectors and the scanners play a significant role in determining the system parameters such as spectral operation band, sensitivity and spatial resolution. The electronic circuitry also plays a key role over the entire system performance. Noise considerations within the electronics play a significant role over the system electronics parameters. Displays, human perception and/or automated target recognizers complete the cycle of operation and conduct the outputs of the entire system to the end user. Thus, these interfaces are of specific importance to the user compatibility and overall imaging system performance [19].

E. OPTICS AND VIDEO TECHNOLOGY: IMAGE PROCESSING

With digital cameras and camcorders, image processing refers to the techniques used to convert raw digital data from the image sensor to a video-compatible signal, which is then ready to be compressed or sent to a display. In addition, the image processing section, which is also called the image pipeline, computes meaningful statistics to assist in auto-exposure, auto-focus and auto-white balance.

Basic image processing consists of three classes: sensor data processing, color conversion and noise reduction.

1. Sensor Data Processing

Three types of color sensors are used in the industry, each with different strengths and weaknesses. The most prevalent sensor in digital still cameras (DSCs) is the RGB sensor; R, G and B stand for the three primary colors. In RGB sensors, a color filter array is placed on top of the sensor; the most common color pattern is called a Bayer pattern and is illustrated in Figure 15.

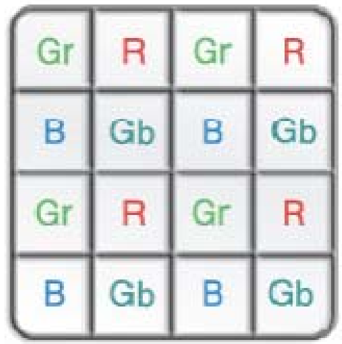

Figure 15. RGB Bayer Pattern (From [20])

In camcorders, two other types of sensors are commonly used: CMYG sensors and 3-CCD sensors. The CMYG sensor uses the complementary primary colors: cyan, yellow and magenta and green. The advantage of this sensor is that is has increased light sensitivity but at the expense of diminished color sensitivity. Therefore, the CMYG sensor is used primarily for low-end cameras with very small sensors and is usually considered unsuitable for still image capture. A 3-CCD sensor, combined with optical beam splitters, is used in high-end camcorders and combines light sensitivity and color sensitivity but at the expense of system cost, size and power. Therefore, 3-CCD sensors are usually limited to small optical sizes and are not typically used in still photography.

RGB Bayer sensors are theoretically capable of recovering most of the resolution in the sensor. In the processing stage, much of the spatial and color information can be recovered using the entire modern digital signal processing (DSP) techniques including classical multi-dimensional signal processing, directional interpolation and multi-channel techniques [20].

2. Color Conversion

The raw data coming from the sensor is a linear function of the photon count in a sensor, while the final video signal must conform in its colorimetry to the international standard for video, including Gamma correction using algorithms for rendering true brilliant colors from the raw data in the image processing.

3. Noise Reduction

Clearly, low-light performance is a very important issue in digital photography. In low light, the low photon count per sensor cell results in a low electrical signal. The influence of both electrical noise and photonic noise results in an extremely noisy image. While the ideal solution is to increase the sensor cell size or the number of available photons (i.e., use a flash) to reduce the noise level, visual impact and interaction with compression algorithms can be done with advanced signal processing techniques: edge-preserving noise reduction and spatio-temporal filtering [20].

4. Auto-White Balance, Auto-Focus and Auto-Exposure

While professional users might want to use manual tuning to achieve a personal trade-off, it is the expectation that today's digital cameras and camcorders will have automatic functioning that is not only truly automatic but also extremely accurate. This means achieving often better results than all, but the most trained professionals can achieve using tiresome manual controls. Extensive statistics are calculated at very high speeds by the image processing section and are then made available to the central processor. The end result is that excellent results can be achieved of various camera manufacturers, while preserving the ability to address the experiences, and tastes [20].

5. Color Night Vision as a Critical Information Multiplier

Apparently there is a manufacturer producing a quality camera, whether CCD or CMOS, for every application. Imaging solutions are being found in almost every possible photonics area, from biomedical to military and aerospace, from the laboratory to homeland security, while camera selection never has been greater and variable features such as speed, resolution and output requirements give the end user a wide variety of performance options from which to choose, one area is growing at a much slower pace is color [21].

In the context of Automated Target Recognition (ATR) schemes, Color Night Vision Systems present the capability for robust positive target identification techniques.

One related concept is demonstrated on digitized imagery by utilizing multi-spectral edge detection in conjunction with region of interest histogram algorithms [22].

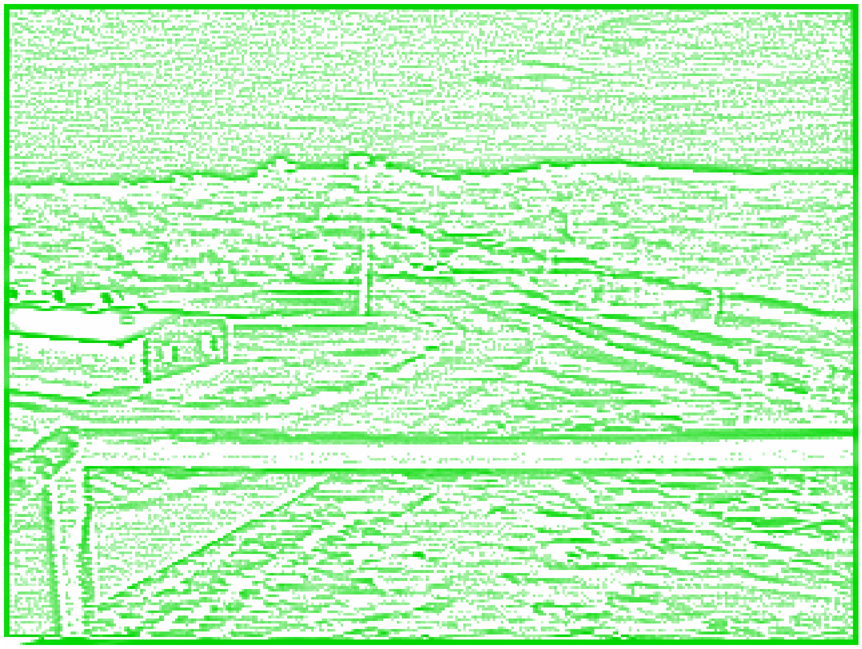

Figure 16. Edge Detection Results on the Standard Green Image (From [22])

The independently analyzed RGB channels of the color image were combined to construct the edge detection results for the color image. This method makes means for secondary verification of targets available. With the traditional method of cross-sectional profile percentile matching, not only probability statistics can be calculated, but also additional information about color content of the targets can be included in the identification scheme in order to increase the confidence in positive target identification [22].

Figure 17. Edge Detection Results on the Color Image (From [22])

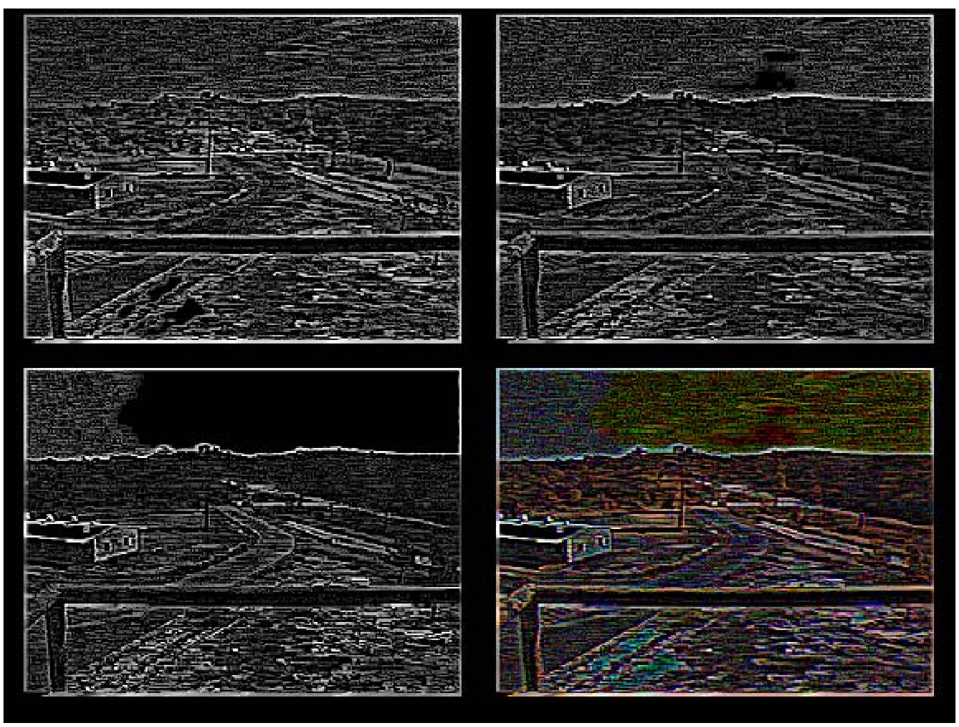

Figure 18. Edge Detection on the RGB Components and the Constructed Multi-spectral Resultant RGB Composite Edge Detection Image (Row Wise, Left to Right: Top Row = R, G, Bottom Row = B, RGB) (From [22])

Histogram information of standard night vision imagery basically gives the distribution of intensities over the entire image. In the digital area, this translates into the number of pixels present at each intensity represented in the image [22].

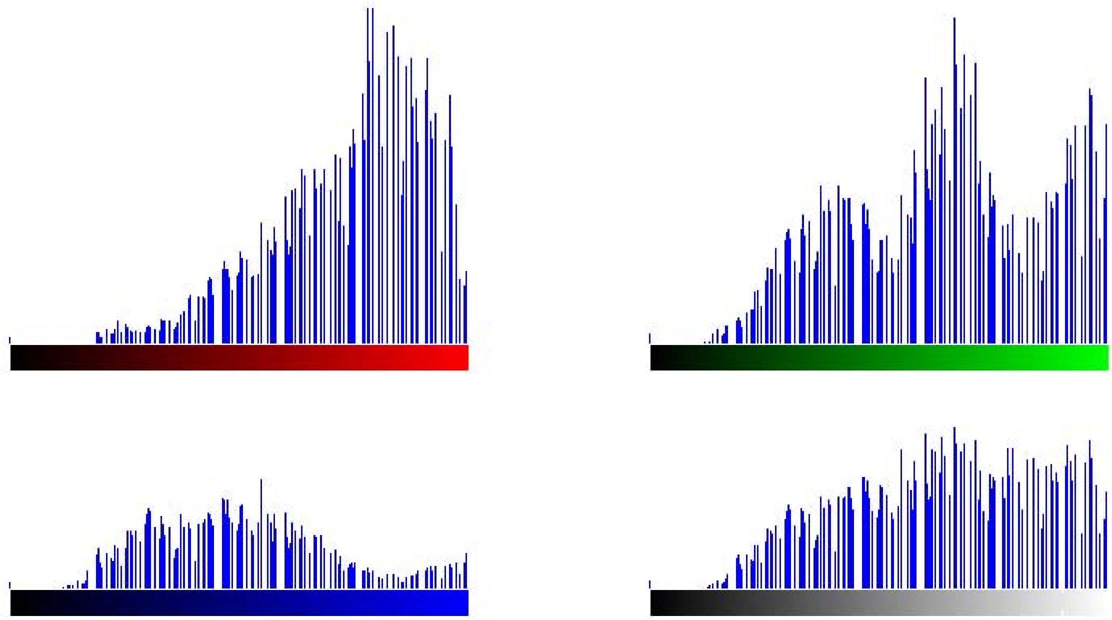

Figure 19. Histograms (Row Wise, Left to Right: Top Row = R, G, Bottom Row = B, and Monochromatic Representation) Illustrating the Information Content in Color Night Vision Imagery versus Monochromatic Night Vision Imagery (From [22])

The color information can be used as an additional identifier of the target by combining the methods of edge detection and area histogram. The color content of the area defined by the calculated contours can further identify a region defined by cross-sectional profile. The contour information is utilized by another similar approach to define a region of interest and display only pixel elements of a specific color or range of colors [22].

In case of ATR, Color Night Vision imagery has the potential of submitting a series of capabilities that both extend the usefulness of existing approaches as well as creating new applications that can result in the positive identification of targets in the tactical nighttime environment.

F. IMAGING SYSTEMS USED IN CAMERAS

1. What is a Charge-Coupled Device (CCD)

A small, rectangular piece of silicon is used to receive incoming light by a CCD camera rather than using a piece of film. This is a special piece of silicon called a charge-coupled device. This silicon wafer is a solid-state electronic component that has been micro-manufactured and segmented into an array of individual light-sensitive cells called photosites. Each photosite is one element of the whole picture that is formed. Therefore it is called a picture element, or pixel. The more common CCDs found in camcorders and other retail devices have a pixel array that is a few hundred photosites high by a few hundred photosites wide (e.g., 500x300, or 320x200), yielding tens of thousands of pixels. Since most CCDs are only about 1/4" or 1/3" square, each of the many thousands of pixels are only about 10 millionths of a meter wide [23].

The CCD photosites accomplish their task of sensing incoming light through the photoelectric effect, which is a characterization of the action of certain materials to release an electron when hit with a photon of light. The electrons emitted within the CCD are enclosed within nonconductive boundaries, so that they remain within the area of the photon strike. As long as light is allowed to intrude on a photosite, electrons will accumulate in that pixel. When the source of light is extinguished (e.g., the shutter is closed), simple electronic circuitry and a microprocessor or computer are used to unload the CCD array, count the electrons in each pixel, and process the resulting data into an image on a video monitor or other output media [23].

The difference between a CCD camcorder and an astronomical CCD camera is that a camcorder must take and display 60 sequential images per second to replicate motion and color from daylight scenes, while an astronomical camera is used to take long-duration exposures of very dim starlight to replicate an apparently motionless object. Camcorders make color images by merging the data taken simultaneously by groups of adjacent pixels covered by red, green and blue filters. Astronomical CCD cameras also can make color images, but post-exposure processing makes these and merging of three separate exposures of an object made through red, green, and blue filters [23].

Finally, there are two characteristics of CCDs which are factors that must be considered in making a final astronomical image:

- Since they are electronic components, CCDs are sensitive to heat within the camera as well as light from the object of interest,
- The individual photosites in the CCD array may vary significantly in their sensitivity to both heat and light.

First, this means that the electrons generated by heat rather than by light need to be subtracted from the final count of electrons in each pixel so that a truer image can be rendered. This is called dark subtraction. Second, the variance in electron depth across the CCD array due to inherent differences among the pixels needs to be leveled by dividing each pixel value by the array's average pixel value. This is called flat fielding [23].

By subtracting a dark frame from the object image results in dark subtraction. Taking an exposure while the CCD is maintained in complete darkness creates the dark frame. The exposure must be the same duration as the light frame and be made with the CCD at the same temperature as during the light frame. So those electrons generated during the dark frame replicate the heat-generated electrons existing in the light frame Flat field images are made by taking a picture of an evenly illuminated scene, such as the sky at dusk or the flat gray interior of an observatory dome. The resultant image shows the inherent variances in pixel value across the CCD array due to differences in photosite sensitivity or to dust specks or vignette in the optical system. An image processing software uses mathematical algorithms to divide all pixel values in the flat field image by the array's average pixel value. The results are then correlated pixel by pixel against the array values in the light image to produce a better representation of the object of interest [23].

In the final stages of image production, the light frame (object image) is adjusted by first having an appropriate dark frame subtracted and then, having an appropriate flat field divided into the image. This process is called image calibration and results in a truer, less noisy image [23].

2. Single Sensor Electronic Imaging Systems

Single-chip area scan cameras use a single sensor that is covered by a color filter with a fixed, repetitive pattern. To reconstruct a complete color image, an interpolation is necessary. The red, green and blue information is interpolated across several adjacent cells to determine the total color content of each individual cell, therefore providing less color accuracy than 3-CCD [21].

In single sensor electronic imaging systems, scene color is acquired by sub-sampling in three-color planes to capture color image data simultaneously for red, green and blue color components. Usually this is accomplished by placing a color filter array (CFA) over a 2D sensor array. A type of CFA called the Bayer pattern is shown in Figure 20.

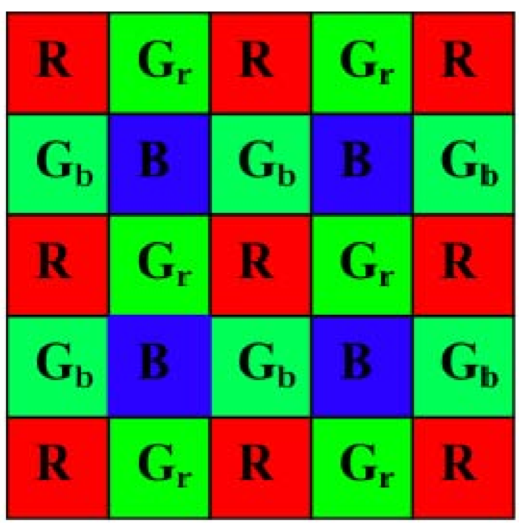

Figure 20. Color Filter Array with Bayer Pattern (From [25])

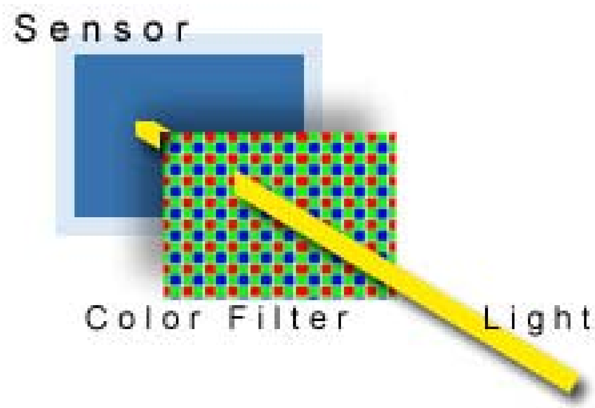

Figure 21. Single CCD System (From [26])

3. Three Sensor Electronic Imaging Systems

3-CCD cameras contain three separate image sensors and a prism that divides the incoming light rays into their red, green, and blue components. Each chip then receives a single color at full resolution, providing the best color accuracy available (Figure 22).

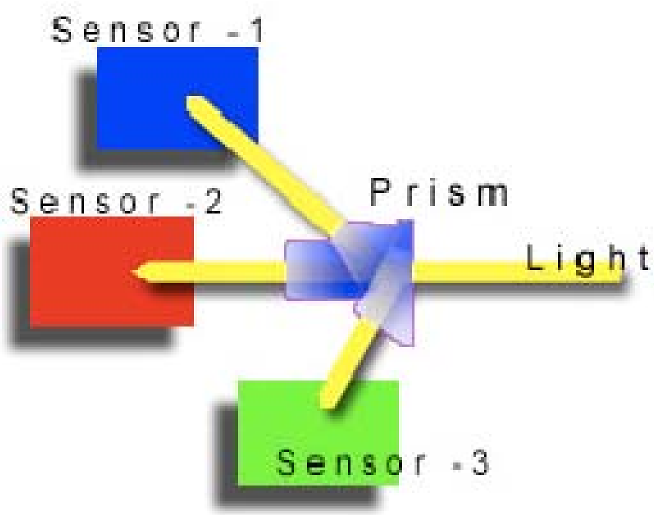

Figure 22. 3-CCD System (From [26])

3-CCD cameras are mostly used in scientific imaging, broadcast, factory automation and industrial video markets. Although the applications requiring 3-chip color camera technology are far less demanding than the traditional single-chip cameras, they are gaining popularity in many vertical industries [21].

Since 3-CCD cameras provide more accurate color images than single chip cameras, 3-CCD systems will facilitate detection of the objects and humans.

G. DESIRED FEATURES FOR CAMERAS

1. Zoom

The purpose of zooming in a video camera is to obtain more detailed visual information than the full frame view. The optical zooming mechanisms make available this additional information. However, when optically zoomed, the camera no longer detects the full frame view that was detected before zooming. Digital zooming can detect the full view at all times, but fails to provide additional visual information when zoomed. In applications such as visual surveillance and manufacturing quality measurement, it is necessary to detect the full frame view at all times. Then again the camera should be able to provide additional visual information when zoomed to the region of interest (ROI) [25].

From this point of view, the desired zooming feature of cameras for applications such as aerial surveillance needs to incorporate properties of both optical zooming and digital zooming. Advantages and disadvantages of both choices should be traded off in order to realize some kind of a design to make maximum available use of both while minimizing the cons of each.

2. Pan Tilt Zoom

One of the highly desired features for cameras targeting surveillance and video monitoring applications is automatic pan tilt zoom (PTZ) capability. One of the common solutions is to employ a computer controlled PTZ moving camera. However, this solution requires high maintenance cost due to movable parts incorporated on the camera platform for mechanical pan and tilt capability. Optical zoom lenses are also expensive and difficult to maintain. Apart from the cost, region of awareness is also an important factor in a camera deployed for surveillance and monitoring. Region of awareness (ROA) represents the field of view that is constantly monitored by the camera. At a particular instant in time, a camera with an optical zoom would have a small region of awareness, especially when fully zoomed to the region of interest. ROI is the area that is displayed on the output video. Usually, ROA is expected to be much larger area compared to ROI. However, with an optical zoom camera, ROA equals to ROI at any point in time. In order to monitor a large ROA while zooming to a smaller ROI, electronic PTZ should be implemented. In this case, the ROA remains constant, while ROI is scaled to fit the output video frame size. ROI scaling up usually causes video blur and worsening of image quality, compared to the optical zoom solution that produces the same resolution and image quality at all zoom levels. One method of enhancing the electronic zoom resolution is to use a very large image sensor array or deploy several cameras to capture the ROA. Using several cameras incur additional cost and computational overhead in image stitching and registration as well as in camera calibration [28].

Electronic zoom may provide us an ROI as large as the ROA while keeping this ROI as small as that of the highest zoom level. The output frame is most likely to be smaller than the captured frame if full ROA is to be displayed in the video. Down sampling of the input data is required in case of full ROA displaying. In fact, up sampling is necessary at higher zoom levels in order to map the ROI to the output video frame.

A popular method of electronic zooming is to produce the full color image frame of the total ROA and selecting the ROI window for up/down scaling to fit the output frame. However, this method involves needless computations on color reproduction in the areas out of the ROI and performs scaling on already color interpolated input video frame [28].

3. Platform and Image Stabilization

Imaging systems is used to convert radiation into images. For example, visible-light digital cameras translate visible light into a digital signal that is used to produce a visible image. Besides, infrared digital cameras translate infrared radiation into a digital signal that is used to produce an infrared image. Unfortunately, images produced by such imaging systems may suffer from a variety of shortcomings, potentially causing a lack of clarity or detail in the images when increased clarity is desired. For example, images acquired from a moving platform such as an airborne platform mounted to an airplane, a helicopter or a satellite may be blurred due to vibration or other motions of the platform [8]. In addition, images of a moving object may be blurred due to an inability of the imaging system to track the moving object sufficiently effectively.

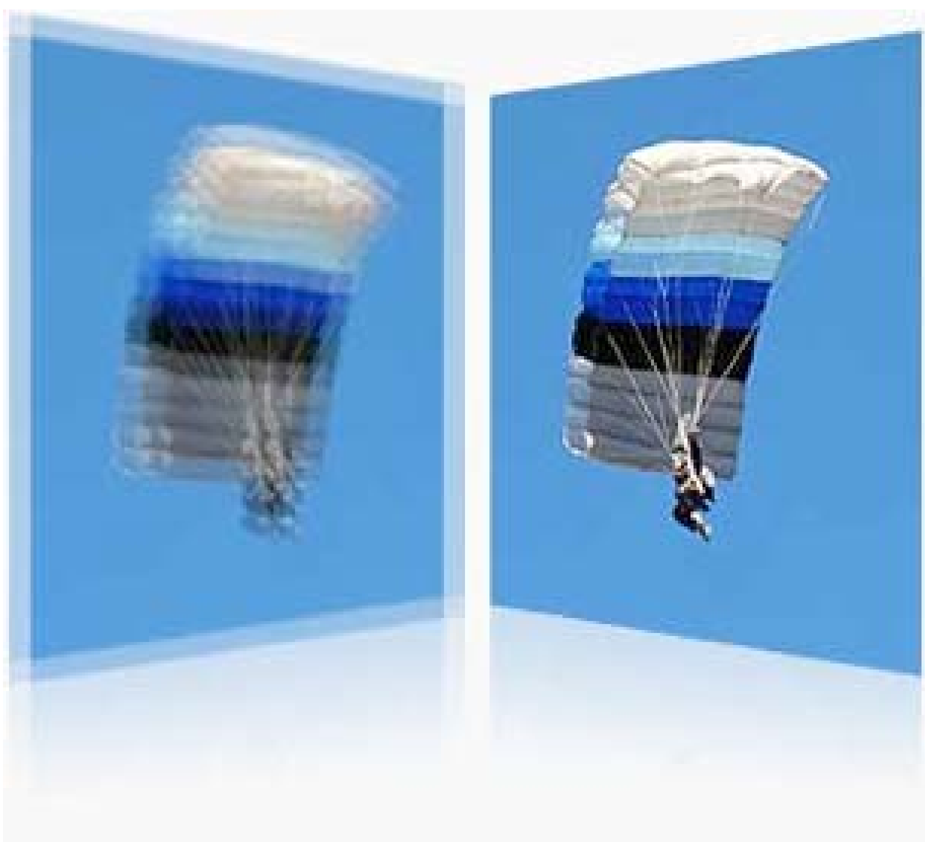

Figure 23. Example Image with and without Image Stabilization

Various image stabilization systems are developed in response to the aforementioned issues. Some of these systems operate by moving a dedicated optical component, such as a mirror or a lens, to produce more accurate images. These dedicated components are also known as stabilization components. They undergo precise movements to acquire additional images to compensate for platform motions or track moving objects. However, the addition of the dedicated stabilization components may require undesirable expense and may take up required space. Given the undesirable expense and space requirements of providing dedicated stabilization components in an optical system may require multiple dedicated stabilization components.

Thus, without requiring the introduction of one or more dedicated new optical components into the system, improved image stabilization systems that are capable of increasing the effective image resolution of an optical instrument, correcting for platform motions or tracking moving targets are needed.

The imaging systems may be used in association with a support platform that includes a support and an optional mounting device. A support generally is any mechanism for holding or carrying an imaging system. Typically, the support is selected to complement the function of the imaging system. For example, an imaging system can be supported by a moving support such as a helicopter, airplane, balloon, boat, car, truck, and satellite. A flying or orbiting support, such as a helicopter or satellite is used for airborne imaging, whereas a terrestrial support, such as a car, truck or motorcycle is used for ground-based imaging. Additionally, an imaging system can be supported by a stationary support, such as a fixed observation tower or platform. The support medium can pass vibration onto the sensor system. This vibration can be lessened or removed by using a sensing device like a gyroscope. Besides, a mounting device generally is any mechanism for connecting an imaging system as well as other components to a support. A mounting device can be configured to position or aim the imaging system in relation to the support. For example, a gimbal system can be used to mount an imaging system to a support. A gimbal system generally consists of any device-mounting mechanism that includes at least two different axes of rotation. Thus it provides angular movement in at least two directions. A gimbal system is configured to rotate a payload about any suitable or desired number of axes, including two axes, three axes, four axes, five axes, six axes, or even more than six axes. In some cases, the mounting device may be used to allow pitch, yaw or roll by system components. Consistent with this flexibility, a gimbal system can be used with an imaging system including one or more still cameras, motion cameras, ultraviolet cameras, visible-light cameras, infrared cameras, and/or compasses, among others.

Some payload components occupy a relatively large volume. For example, camera lenses can be fairly large when designed to provide magnification or to work in low-light conditions. Such payload components can occupy all of the payload capacity that a gimbal system provides. Therefore, it is desirable to design gimbal systems with increased payload capacity. So that larger or more payload components can be accommodated by a single gimbal system. Likewise, it is also desirable to decrease the volume a device requires to perform a desired function effectively freeing space for other devices. Lowering the cost of manufacturing an imaging system and associated support platforms is also desired.

Figure 24. A Gyroscopic Stabilizer (From [29])

Lastly, using gyros, gimbals and privately developed control technologies, platform and image stabilization are made feasible in order to provide accurate surveillance from the earth to the sky. Consequently, gathering usable imaging from vessels, helicopters, aircraft and orbiting satellites is possible.

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IV. TYPES OF VIDEO CAMERAS

A. THERMAL CAMERAS

1. General

Night Operations in the thermal infrared (IR) bands are supported by a variety of forward-looking infrared (FLIR) imaging devices (both scanners and IR focal-plane arrays) displayed on monitors, the cockpit heads-up display, or combiner optics [30].

Thermal cameras aim to provide the user day view conditions – to the most available level – in night view conditions. They contribute security systems and personnel by providing the capability to monitor objects or threats that are invisible to naked eye at night conditions

Thermal cameras observe the environment by turning heat into visible image via a monitor. They create pictures by transforming heat energy into visible images that are invisible to naked eye. Figure below presents the difference between a normal view and a thermal view of the same frame. As it can be seen from the thermal image, everything in the color image is producing heat.

Figure 25. Thermal Image

Since all objects generate heat, thermal cameras are able to change night into day with a clear vision. When additional illumination is not available, light dependent cameras have no use at night or in poor visibility conditions.

Figure 26. A Standard Camera and an Thermal IR Camera

Thermal cameras also incorporate the ability to see through obscurants like smoke, dust, modest foliage and light fog. As seen in the figure below the thermal camera shows everything clearly while a standard color camera cannot in daylight foggy conditions [31].

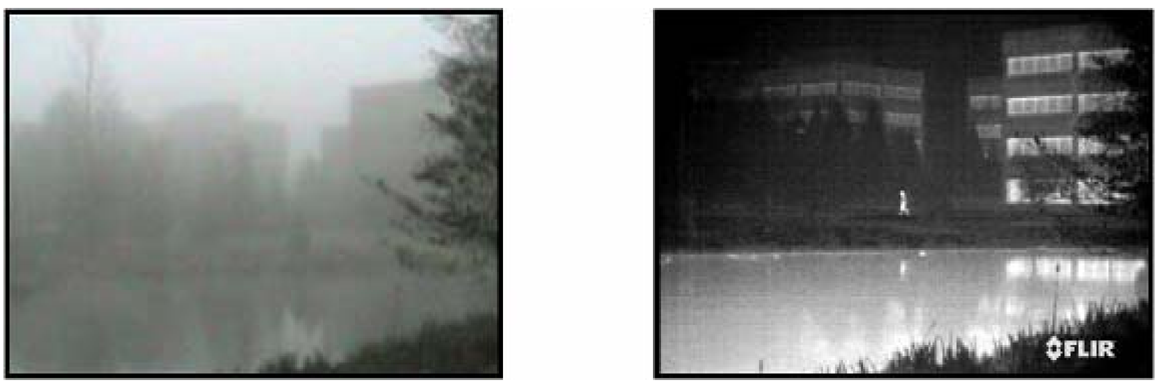

Figure 27. Obscurants and Thermal Cameras

Thermal cameras maximize the detection of objects or threats. Most of the time, thermal energy travels through the atmosphere more effectively than visible light. Thermal cameras are able to observe threats, objects, and activities at relatively high ranges when compared to standard light and color dependent cameras [31].

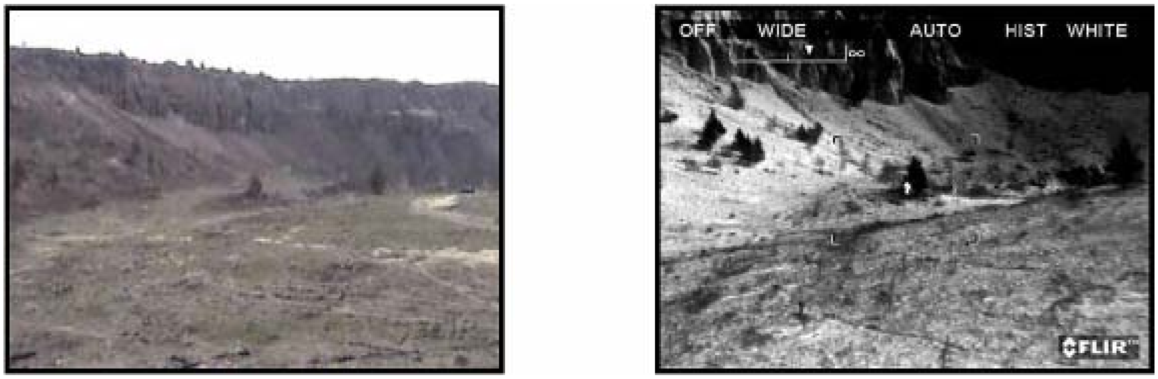

Figure 28. Daylight and Thermal Camera Together

Thermal cameras can be used to compliment daylight cameras. Thermal cameras can be used to detect threats that cannot be observed on the daylight camera, which may be camouflaged as shown in the figure below. Standard daylight cameras depend on color contrast to provide imagery for detection of any kind of threat. Thus weak color contrast may result in undetected threats within the range of the camera. Since thermals cameras are not limited to color contrast, they help the observers to see more during the day [31].

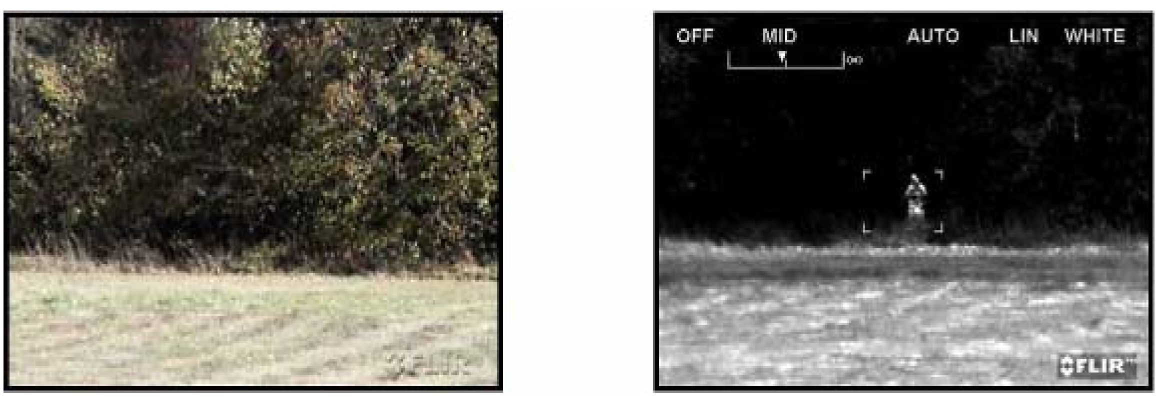

Figure 29. Color Contrast Limitation of Day Light Cameras

2. Applications of Thermal Imaging

a. Port Security

When port security is considered to be physically complete, adequate illumination for waterways, waterfronts and water lands is a great challenge, which is a prerequisite for operation of standard light dependent cameras. Thermal cameras eliminate this trouble by providing desired visibility without being dependent on illumination or any other kind of artificial lighting.

Figure 30. Port Security with Thermal Cameras

b. Areas Too Large to Illuminate

Some areas like borders, dams, refineries, and airports include a large amount of land sometimes miles of real estate besides requiring a great need and effort for high-level security. With their ability to cover very long ranges, thermal cameras provide effective solutions for these kinds of missions by eliminating the need to illuminate such areas [31].

Figure 31. Large Perimeter Security with Thermal Cameras

c. Lighting Unwelcome Situations

In some cases security concerns may particularly require no illumination or illumination may increase the vulnerability of the place to be protected against security risks. In such situations requiring non-lightning conditions for security and secrecy concerns, thermal cameras provide excellent solutions in detection of security threats or any kind of hostile activities.

d. Long-range Detection

As mentioned previously, thermal energy eliminates obscurants better than visible light by intruding through them. This ability makes thermal cameras an excellent solution conditions of smoke, dust, light fog, etc. In addition, elimination of obscurants gives the ability to detect long-range activities and threats to thermal cameras [31].

Figure 32. Obscurant Elimination and Long Range Detection

e. *Applications that Require More Information than the Eye Can See*

Thermal cameras provide the ability to detect activities about a scene that cannot be detected by naked eye most of the time like open windows, or recently parked cars [31]. This enhances situational awareness and extremely increases the security to high levels.

Figure 33. Congested Areas with Thermal Cameras

f. *Critical Infrastructure*

Thermal cameras are valuable tools for critical infrastructure like nuclear power plants to provide high-level security. Since, these kinds of facilities require extremely high level of security and there is no room for mistake, thermal cameras eliminate the range and lightning drawbacks of conventional light-dependent cameras [31].

Figure 34. Critical Infrastructure and Thermal Cameras

B. ELECTRO-OPTIC CAMERAS

For more than 30 years electro-optical cameras are installed in satellites around the earth at altitudes of several 100 kilometers. These cameras have been used for remote sensing and mapping purposes in both commercial and military applications.

Electro-optical cameras are used for port, harbor and border security, surveillance, tracking and intrusion detection and even in satellite tracking. They provide stabilized, long-range and automated electro-optical imaging for surveillance purposes. The demand for electro-optical systems is increasing because they provide long-range, repeatability and automatic repositioning capabilities besides stability, accuracy, endurance and high performance [32].

Figure 35. A Satellite Tracking Electro-optical System

Electro-optic cameras provide very reliable solutions for surveillance and sensing tasks. They are widely used for immediate and online environmental monitoring for detection of activities and threats to satisfy security concerns. Online and immediate monitoring brings the capability to evaluate image quality and immediate corrections can be performed. The features of the image quality like contrast, brightness, etc can be manipulated easily digitally and online to achieve a better view of the ROI. Digital data captured by electro-optical camera may also be stored in digital formats for further analysis.

Certain processing steps can be automated during plotting of images taken by electro-optical cameras. The image data is available in digital or digitized form. Some of the procedural steps that can be automated include interior orientation, digital aero triangulation, image rectification, the generation of orthophotos and digital terrain models, image and map superimposition, and updating comparisons. Future automation of further steps will increase the need for electro-optical cameras [30].

Figure 36. Electro Optic Camera View

Electro-optical cameras fall into two categories depending on the detector used. The types of these detectors are area detectors and strip detectors. Both types have their own pros and cons. Electro-optical cameras equipped with CCD area detectors emphasize on stabilization but they have less ground coverage. An electro-optical camera equipped with a CCD strip detector provides better ground coverage than a CCD area detector, but it requires much better stabilization than an electro-optical area detector camera [30].

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V. TESTING OF ALAN CAMERA AND RESULTS

A. TEST AND EVALUATION PLANNING

Test and evaluation planning includes resources to execute a proposed test. It also determines types and quantities of data needed, results expected from the tests and analytical tools needed to conduct the tests and evaluations.

Accordingly, test and evaluation process is executed in order to find out that a product or systems meets the requirements considered compulsory. Therefore, any system or product must undergo two types of testing. First type of testing is development testing which is done in a controlled environment to ensure that all system or product components meet technical specifications and criteria. This testing is normally done by the developer of the system or product and includes the qualification testing of components used in the system. Second type of testing is operational testing conducted by representative users in real world operational scenarios that replicate actual use of the system or product. These kinds of scenarios are conducted in realistic field conditions and full range of climatic conditions in the same way as the field experiments are performed by the NPS COASTS program.

Operational testing mentioned above requires that a test plan is prepared before a system undergoes any type of testing. The test plan is the set of ideas that guide or represent the intended test process. It is intended to be specific to any equipment or configuration. The plan can be made as simple or detailed as necessary depending on the system or technology involved. Consequently, a test plan was prepared for each field experiment in order to test ALAN camera. They are presented in the following sections of this chapter.

Concurrently, ALAN camera test planning was completed considering the following sequence.

First of all, the need for low-light sensor technology or ALAN camera for the purpose of providing ISR was explored and stated briefly in the following sections of this study. In addition, the operational environment in which ALAN camera is to be used was taken into account and thus, several testing of the camera was assessed as necessary.

Subsequently, ALAN camera description including key features and subsystems allowing the system to perform its required operational mission is given later in this chapter. Equipments essential for configuration setup are also listed and their characteristics are explained briefly. This information is considered as necessary and helpful in order to list the operational effectiveness and performance capabilities and characteristics.

Critical operational issues were also taken into consideration while planning tests. Critical operational issues are the operational effectiveness and operational suitability issues (not parameters, objectives or thresholds) that must be examined in operational test and evaluation to assess the system's capability to perform its mission. Examples of operational suitability may include considerations such as size, weight, packaging/transport requirements, power, personnel safety, etc. A critical operational issue is typically phrased as a question that must be answered in order to properly evaluate operational effectiveness (e.g., "Will the system detect the presence of an intruder at an adequate range to permit successful engagement?") and operational suitability (e.g., "Will the system be safe to operate in a harsh environment?").

Then, MOP and MOE that the test and evaluation was based on could be defined more realistically. MOP and MOE are also explained later in this chapter. The metrics were selected considering objectives and technical parameters of the ALAN camera as well.

Test program schedule was fully dependent on the COASTS FEX schedule. Since FEXs are performed during weekdays, ALAN camera testing was planned for each day. The detailed timelines, objectives and required personnel for testing are stated in the test plans for each FEX.

Analysis was done as to how the test was to be conducted. Consideration was given to the type of resource to be used, the personnel who would operate the ALAN camera and balloon (the system), the environment under which the system would be employed, the availability of documentation of the ALAN camera, how interoperability and compatibility with the COASTS network would be accomplished, and how the test scenarios would be conducted were studied. However, the development testing information for the ALAN camera could not be used for the purpose of comparison due to it not being available. Test support equipments (e.g. laser range finder, light meter, laptop, balloon frame, radios) that must be gained specifically to conduct the test program were identified. A brief summary of how the tests were planned is provided later in this chapter.

Subsequently, the most appropriate test location was selected in the area where the COASTS experiment was being conducted, in this case McMillan airfield at Camp Roberts, California. The runway of McMillan airfield was considered as the best option due to an available area for balloon operations. During the test planning period, a limited operational environment for airborne low-light testing of ALAN camera was the main constraint. The limitations at the test location restricted available time and locations to plan and execute airborne low-light tests.

Lastly, a summary of test results were provided according to tests executed during FEX II and I.

B. KESTREL ALL LIGHT/ ALL NIGHT (ALAN) CAMERA TECHNOLOGY OVERVIEW

1. Introduction

Kestrel Technology Group, LLC of Sugar Land, Texas provides low light video surveillance solutions using advanced sensor technology referred to as ALAN (All Light / All Night) cameras. These sensors insert a series of amplification gates between the sensor pixels photon charge sensing mechanism and the output amplifier of the chip. These amplification gates multiply photonic generated charge in several steps to produce an image intensifier effect that enables full motion color at low light levels with low noise [33].

The benefits of this technology for surveillance include:

a. Increased Low Light Sensitivity and Detail

The ALAN camera can be advantageous for identifying entities in urban and covert surveillance by providing additional information detailed below:

- Color of clothing
- Personal characteristics, hair, skin, etc.
- Lettering / license plates
- Vehicle specifics
- Carried items [33]

b. Natural Interpretation of the Image

The ALAN camera increases performance of human and automated video analysis/analytics by presenting natural interpretation of the image:

- Color images provide natural depth perception assessment
- Wide panoramic shots produce more detail from the environment without the need of a powerful illuminator
- Monochrome thermal images often lack visual cues for depth interpretation
- Thermal depth and distance may need trained operators to interpret [33]

c. Versatile and Cost Effective

Versatility and cost effectiveness are benefits of ALAN camera considering the following list:

- Excellent day as well as night performance
- Unique versatility produces a high performance one camera solution
- Passive sensor operation requires no auxiliary illumination, limiting factor is lens optics and atmospheric contamination over distance [33]

The ALAN camera can produce full motion full color images far down into low light intensity levels where other technologies encounter performance barriers. Entering the low light level spectrum, standard CCDs or technologies such as thermal or CMOS are producing monochrome images with higher and noise and/or smear (CCD and CMOS) or with lack of detail negatively impacting ease of human depth perception (thermal) [33].

This additional color and motion capability from an ALAN camera can be processed by intelligent video analysis, and is more easily interpreted by operators for location of objects in wide-angle panorama. This can be a valuable tool where as much personal detail as possible provides for better real time response such as in urban counter terrorism, counter narcotics, challenged biometrics and force protection / tactical approach [33]. The environmental configuration allows ALAN cameras to provide improved capabilities for rapid deploy and harsh environments.

2. DESCRIPTION: MOBILE/TACTICAL ALAN SURVEILLANCE CAMERA

a. General Information

The Kestrel Mobile/Tactical ALAN camera is designed for surveillance applications where color full motion images in low ambient light conditions as well as high quality daytime images are a requirement. It is designed for deployment in tropical/equatorial/marine environments for extended periods of time with low maintenance requirements. The system is designed with optics matched to the ALAN camera sensor and system housing to produce optimized image performance in a compact size. The unit has an extruded main aluminum case with machined end plates to allow a gasketed environmental seal. Active cooling is employed to deal with environmental temperatures well in excess of the electronics' environmental tolerance [33]. With the help of these specifications, ALAN camera performed very well and provided continuous high detailed video feed to Tactical Operation Center (TOC) during the COASTS-07 field experiments especially in Thailand despite harsh weather conditions.

Figure 37. The Kestrel Mobile/Tactical ALAN Camera

b. General Specifications

The Kestrel ALAN camera provides low light and daylight color video using advanced sensor technology. These sensors insert a series of amplification gates between the sensor pixels photon charge sensing mechanism and the output amplifier of the chip. These amplification gates multiply photonic generated charge in several steps to produce an image intensifier effect that enables full motion color at low light levels with low noise. Thus, ALAN camera can produce effective full motion color images down to 20 millilux with minimal smear.

Considering diverse operating environments where an ALAN camera has to function, it is designed with a rugged enclosure with active cooling for higher temperature environments. Industrial hard coat anodized finish and subsea grade connectors make it appropriate for operations in corrosive environments.

Optimized size and weight is another specification that is proper for transportation or rapid deploy perimeters. Impact resistance housing also results in low maintenance requirements for the ALAN camera.

Pan, tilt, zoom, focus and IP network capabilities are other useful features of the ALAN camera. For rapid deploy use, military type field batteries can be used for power supplies.

ALAN cameras come with standard 6x zoom capable 4 to 48 mm lens that is effective up to 500 meters. In addition, there is an optional 22x zoom capable 9 to 200 mm lens that is effective up to 1.5 km.

The imaging format of an ALAN camera is native National Television Systems Committee (NTSC) or 470 Television lines. It can also be a Phase Alternating Line (PAL) interface at 520 lines of resolution [33].

In order to operate ALAN cameras, external equipment is required. These consist of an IP server/encoder, external RS-232 Zoom/Focus/Iris lens control, DC compatible power supply and environmental enclosure.

Figure 38. External Electronics

C. EQUIPMENT

1. Equipment Required to Connect ALAN Camera to the Network

a. Axis 243S Video Server

The digital server used during the tests is a high performance Axis 243S The Axis 243SA Video Server enables high resolution, full frame rate video surveillance and remote monitoring in MPEG-4 and Motion JPEG. The video server converts analog video into high quality, de-interlaced digital video, and can deliver the highest resolution, 4CIF, at 30/25 (NTSC/PAL) frames per second [34]. The image is encoded as a webpage that allows viewing over the web with an ordinary browser via an Ethernet IP connection.

Figure 39. Axis 243SA Video Server (From [34])

Using motion JPEG consumes up to 20Mbytes/second of bandwidth with no compression and 30 fps at full resolution and MPEG-4 can produce the same quality at about 1/4 that bandwidth or less.

A comprehensive set of security features, including multiple user access levels, HTTPS encryption, possibility to disable unused network services for example ftp, IEEE802.1X and IP address filtering, ensures secure video handling and configuration. In addition, the Axis 243SA has support for Quality of Service (QoS) that helps secure the necessary bandwidth for streaming video and control commands over a network [34].

In addition to features mentioned above, the Axis 243SA Video Server connected to an ALAN camera allows for easy operation of the camera across the IP network [34]. It holds an important role for providing interoperability and compatibility for the ALAN configuration. By using Axis 243SA Video Server, the interoperability and compatibility with COASTS network is made available.

b. Serial Interface Lens Controller

The high performance lenses (less than 1.4 f stop) for 200mm and 50mm versions are controlled by a serial interface lens controller for focus and zoom.

Figure 40. Serial Interface Lens Controller

c. Environmental Housing

The Axis server and lens controller are contained in an environmental housing that has an Ethernet switch with ports to the outside so that external IP radios can be hooked up for wireless connectivity. The housing also has an external alternating current (AC) power supply for 100/240 Volt AC (VAC) operation or battery terminals accepting direct current (DC) power from 9 to 18 volts.

Figure 41. Environmental Housing Configured For ALAN Camera

d. MicroHard Radio Modem

Using the housing external Ethernet ports, CAT 5 cable can be run to a network or to external radios such as Microhard 921's. The Microhard 921's have proven useful for reliable connections up to over 1 mile. These 900 MHz units do not provide sufficient bandwidth for full frame video but have a reliable link and are easy to deploy.

The single direction observed bandwidth of about 2 to 4 fps is usable for many applications. The link includes a capability to control the lens using a Transmission Control Protocol/Internet Protocol (TCP/IP) port session [35].

Figure 42. MicroHard Radio Modem (From [35])

Figure 43. MicroHard Radio Modem Used During FEX I

Figure 44 below shows an ALAN camera being deployed during FEX I. The ALAN camera was set up to feed surveillance video to Tactical Operation Center (TOC) during scenarios at Camp Roberts California.

Figure 44. ALAN Camera and The Equipment Used For Surveillance During FEXI

2. Other Equipment Required

Test equipment consisted of a laptop for testing and recording ALAN camera video, a military field type battery for supplying required power during the planned testing periods, a payload frame for hooking up equipment to a balloon, a balloon to make airborne testing feasible, a light meter to measure and record light level in the environment and a laser range finder to measure the height of ALAN camera were all required to execute proper testing.

D. METRICS FOR TESTING OF ALAN CAMERA

The selection of proper metrics helps ensure a useful experiment and test. Thus, metrics have to be consistent, quantitative and measurable. Considering these helps planned testing procedures to be more meaningful and accurate in approach. In order to determine which metric is good and proper, several common characteristics need to be considered. The first important quality a metric has to have is that it must be observed and monitored in time. This results in a quantitative metric useful for comparing and analyzing test data. The second characteristic of a metric is being able to be benchmarked against similar systems. Comparing benchmarks allow trade-off analysis of related systems. The third one is that a metric must allow testers to take actions in order to keep the observed values inside acceptable range. The last characteristic of a metric requires no change in the metric during the whole measurement and data recording.

1. Selected Metrics For Testing of ALAN Camera

In order to test and evaluate an ALAN camera, the metrics were selected taking both the characteristics mentioned above and the purpose of this study into account.

The first metric selected was the altitude or range that an ALAN camera was able to detect people and units in low light conditions. The fact that detection altitude affects the usefulness of an ALAN camera for ISR missions, the deployment numbers, and the configuration, it can be considered as one of the most important parameters. For instance, if an ALAN camera is being used for the purpose of perimeter surveillance and expected to detect people at 500 meters, it must always have the detection range of 500 meters. Otherwise, it causes an important security risk for the organization.

The second metric selected was the coverage for area of operational interest (AOI). This metric is also important to depict the required number of cameras and discover their operational configuration. Since no organization in the world has unlimited funding, it is required to have the best option for the operational use.

The other metric selected was link quality. Having an efficient link is important for both supplying constant surveillance video feed to the operation center and having healthier image quality. Link quality essentially depends on the wireless equipment employed for connecting ALAN to the network.

Video or image quality is also selected as a metric. This certainly affects the result of the surveillance mission. If a camera cannot provide accurate and continuous image, it is not feasible to employ it in order to discriminate and detect objects.

Another important metric is the time required to deploy an ALAN camera for operational use. This allows users to plan surveillance missions accordingly.

The last metric is the endurance time of the system. The endurance time is considered necessary to plan persistent surveillance mission. Basically, this relies on the power source used other than camera itself.

E. MEASURES OF EFFECTIVENESS / MEASURES OF PERFORMANCE (MOE/MOP)

If it is needed to make rational assessments and selections in product and systems development, having criteria to measure the value or relative importance of characteristics of alternative proposals is needed. This is an essential precondition for part of trade studies. Both the client (customer, user) and the engineer have such measures, and these are related [36].

It is often necessary to measure the relative importance of aspects and compare the over-all quality of a system. Measures of Effectiveness (MOE) and Measures of Performance (MOP) are qualitative and quantitative values that allow for the impartial trade-off analysis [37].

MOE represent the customer view, usually annotated and of qualitative nature. They describe the customers' expectations of a product, project or system. They can be defined as the voice of the customer. MOPs are the corresponding view of the engineer.

They can be defined as a technical specification for a product. Typically Measures of Performance are quantitative and consist of a range of values about a desired point. These values are what an engineer targets when designing the product, by changing shape, materials and manufacturing process, so as to finally achieve the qualities desired by the customer [36].

Both the MOE and the MOP can be constructed as a hierarchy diagram (Figure 45). Each horizontal level of the hierarch represents 100% of the effectiveness or performance.

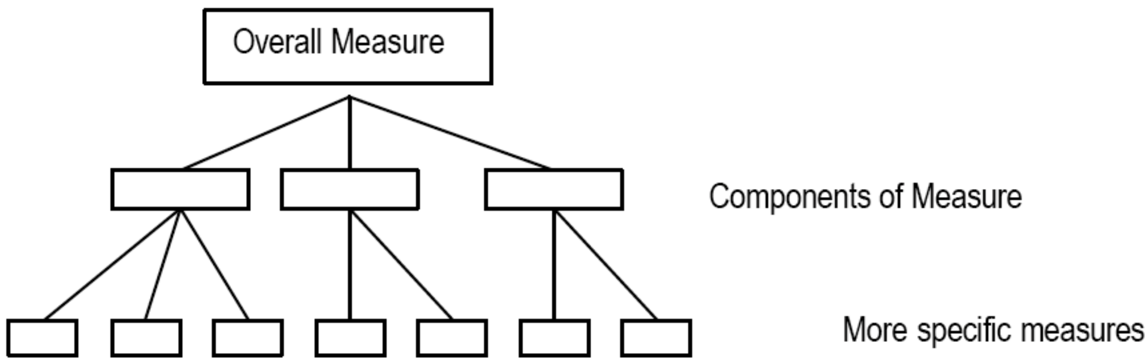

Figure 45. Diagrammatic Representation of a MOE and MOP Hierarchy (From [36])

Many of the results from this method may seem to be logical and obvious requirements. Nevertheless, as the product becomes more complex, the systematic approach of breaking down the customers' requirements into their most basic components helps to understand where requirements were derived. This method enables construction of a complete list of customer needs and wants, from which broad engineering specifications are developed. When developing the Measures of Performance, it is necessary to differentiate needs and wants in the design. These then enables engineering design to continue with some essential known constraints and variables [36].

Figures 46 and 47 depict example Measure of Effectiveness and Measures of Performance.

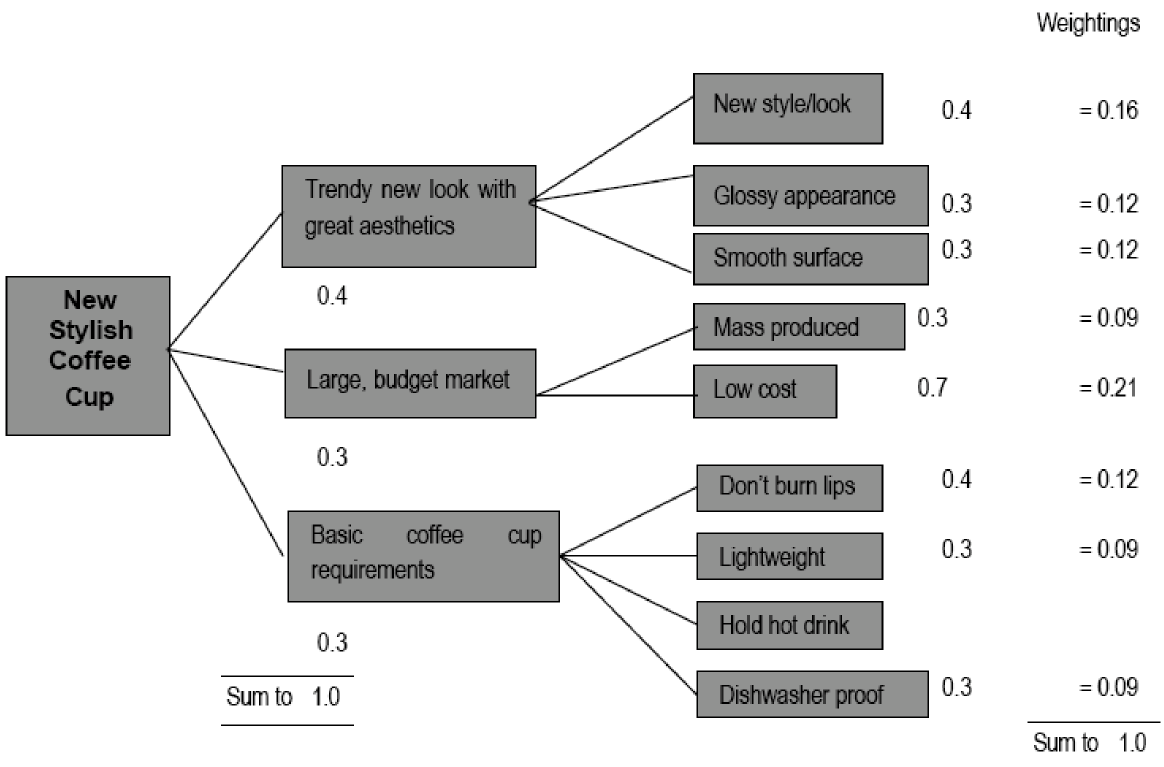

Figure 46. An Example MOE for New Stylish Coffee Cup (From [36])

Need or Want	Specification for **New Stylish Coffee Cup**	Page 1
N	Weight < 120g	
W	< 100g	
N	Non porus	
N	Thermal conductivity < 2.5W/m.K	
W	< 1.4 W/m.K	
W	Surface Finish < +- 0.04mm	
N	Produce > 5000 items/ day	
W	> 8000 items/day	
N	Rigid solid @ ~ 110oC	
W	Reflective coating	
W	Volume ~ 280-350ml	

Figure 47. An Example MOP for New Stylish Coffee Cup (From [36])

1. Selected MOE/MOP for ALAN Camera Testing

The main requirement for illustrating the effectiveness of an ALAN camera during the planned aerial tests is to be able to provide controllable real-time video of the area of interest in low light conditions. In addition, deployability of an ALAN camera on a balloon or UAV and rapid deployment of it are also taken into consideration. Depending on these requirements, MOE are produced. Conversely, the ability to pan, tilt and zoom, data format, wireless connectivity, low light capability under 1 millilux, deployability in 10 minutes, easy configuration and minimal training, the real-time video display, operability in adverse climatic conditions, lightweight, small size and endurance time more than seven days are considered as performance requirements. Consequently MOP are selected appropriately.

The following MOE and MOP shown in Figures 48 and 49 were selected for ALAN camera testing during field experiments.

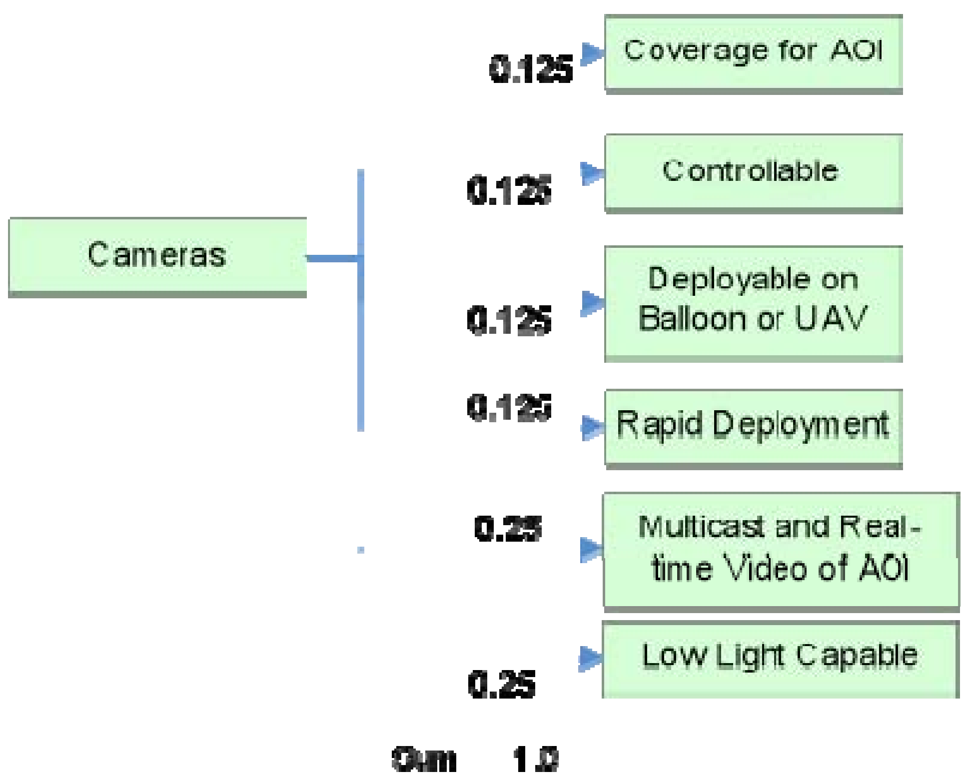

Figure 48. Selected MOE for ALAN Camera Testing

Need/Want	Specification
N	Wireless connectivity
N	Control pan/tilt/zoom
N	Low light capability under 1 millilux
N	Real-time video display
W	MPEG format
W	Deployable in 10 minutes x
W	Easy configuration, minimal training required
N	Endurance time >7 days
N	Lightweight, small size
N	Operate in adverse climatic conditions

Figure 49. Selected MOP For ALAN Camera Testing

a. Light Level Values

Light level is the main factor affecting the image quality. Sharp clear images are produced from daylight downwards until a point is reached when there are insufficient photons to produce a coherent image. The image becomes increasingly grainy at this point. Overcast starlight alone may only show up large areas such as coastlines against the sky.

Light level is expressed in LUX and typical values are:

- Sunlight: 50,000 lux
- Clear moon: 100 millilux
- New moon: 10 millilux
- Starlight: 1 millilux
- Overcast starlight: 100 microlux [38].

F. TEST DESIGN

Appropriately setting-up and designing the tests is essential in order to have correct analysis and conclusions from the results. The planned test should let the testers determine the relationship between input and output. Directly employing the system may result in an effective proof of concept, nevertheless it does not let testers draw reliable conclusions as a result. Proper test design is done in four steps. First, the objectives of the tests need to be defined clearly. Secondly, the independent variables have to be defined. They are required being measurable and controllable. The third step in the design of a test is to determine independent variables. The last step is to execute data analysis in order to draw conclusions.

The tests were designed before the field experiments in order to execute aerial low-light testing and evaluation of an ALAN camera. Since the COASTS scenario to be performed was daytime only, separate airborne testing of the ALAN camera was planned for each FEX.

The aim of the planned tests was to experiment previously defined Measures of Effectiveness and Measures of Performance. Furthermore, the tests planned to focus basically on the range that an ALAN camera is able to detect people and units in low light conditions, the coverage for area of operational interest, link quality, video or image quality, the time required to deploy an ALAN camera for operational use and the endurance time of the system.

Several independent variables were identified. These variables include light level, altitude of the ALAN camera and size of the object. Altitude of an ALAN camera is assumed to affect the detection range. Rising altitude increases the range to detect objects, which is mostly limited by the lens used in camera. In addition, altitude also affects the coverage for area of operational interest and the link quality. Other effective variable is ambient light level. Light level is assessed to affect the video quality and discrimination and detection objects. Higher light levels provide better color images for ISR. The size of the object is also assumed to affect the detection range. Apparently, detecting a larger object is easier than detecting a smaller object. Consequently, using two types of objects were planned during the tests. The first type of object was a human. The second type to be used was a car. The weather conditions such as visibility, temperature, pressure and humidity in the test area are some factors that are not controllable in operational testing. Adverse operating environments results in temperatures ranging from 20^{o} F to $150\ ^{o}$ F, atmospheric pressure from ranging from 29 to 32 inches mercury and humidity varying from 5% to 100%. Due to not being able to control the environment, the values of visibility, temperature, pressure and humidity were required to be recorded to ensure that different environment conditions were experienced.

Measurements of the range that an ALAN camera is able to detect objects in low light conditions were planned to determine the maximum range that the ALAN camera can reliably detect a person or an object in different low-light levels. Range measurement was planned to be in feet from ground level up to balloon altitude. Altitude of the balloon was to be increased gradually allowing measurements at different heights. For this measurement, balloon altitude was to be recorded by a GPS device. In order to provide different light conditions, several tests were planned to get the benefit from different moon illuminations during weeknights since the light level is the main factor affecting the detection of an object. It was also planned to apply artificial illumination sources to increase light level in the test area by means of car lights or a portable lamb.

In addition, measurements of the coverage for area of operational interest were planned to depict the required number of cameras and discover their operational configuration to cover specific areas of interest. The McMillan airfield was considered as the most appropriate place to capture the area measurement. Accordingly, measurements were to be recorded in feet to benefit from the runway signs of McMillan airfield.

Having a reliable link is an important factor to provide continuous ISR information to the decision makers. Link quality essentially depends on the wireless equipment employed for connecting an ALAN camera to the network. Thus, examination of link connections were planned to investigate whether the MicroHard Radio Modem was capable to provide continuous link in order to feed video to the network. Since the complete understanding of MicroHard Radio Modem capability is not the primary objective of this thesis, it is considered that the general performance of the equipment was to be examined during balloon deployment. This was planned via sending ping requests to the Axis video server at constant intervals and checking whether the recorded video from the ALAN camera was interrupted or not.

Additionally, having the accurate video or image plays an important factor in discriminating objects. This certainly affects the result of the surveillance mission. If a camera cannot provide a correct image, it is not possible to discriminate and detect objects under extremely low lighting conditions. For that reason, the video feed from the ALAN camera was required to be recorded continuously for post experiment examination. It was also needed to record the time of the day for certain altitudes to see the exact image quality after the test was completed.

Besides, it was considered essential to record the total time needed to deploy an ALAN camera so as to find out the minimum and maximum time for operational deployment. This allows users to plan surveillance missions accordingly. It was designed to record deployment time including both time to deploy the balloon and time to configure the system. Both measurements were to be in minutes.

The last measurement was the endurance time of the system. A long endurance time is considered necessary to plan persistent surveillance mission. Basically this relies on the power source used other than indigenous to the camera itself. Using military type field batteries as a power source for the payload was expected. Thus, the battery life of the configuration determines the effective on-station time of the ALAN camera. The objective was to discover the endurance time of the system in minutes.

Conduct of the physical test was planned in several steps. The first step is configuring and setting up the needed equipment. The Axis video server and serial interface lens controller are configured and connected to ALAN camera. They are also contained in an environmental housing that has an Ethernet switch with ports to the outside such that an external MicroHard Radio Modem is able to provide wireless connectivity. After powering up the configuration, operational testing of the system is done using a laptop in order to check if video feed is available wirelessly to the network. Unless any problem comes up, the ALAN camera and the environment housing is attached to the payload frame that is previously modified for aerial testing. Next, the payload is transported to the balloon site in order to launch the system. After having winch and balloon ready, the payload is hooked up to the balloon which then becomes ready to launch. The timeline for the whole process is already scheduled taking into account the sunset times. After the balloon reaches the selected altitude, a person and a car (both test objects) are standing at the ready on the runway. Prior to the balloon reaching the first planned altitude, the tester would start recording the video feed from the ALAN camera. When the first planned height is reached, the time and the other data would be recorded in the data collection matrix. The light level is measured using the light meter by the person on the runway and relayed to the tester via radio. If needed, the light level could be altered using an artificial light source in the test area. This process is completed several times for each planned altitude. Deployment time and endurance time are also recorded. In addition, the values of temperature, pressure, humidity and visibility are recorded. According to the test plan, it is planned to repeat these steps as often as necessary throughout the experiment.

G. FEX I TEST PLAN

The test plan to be performed during FEX I included separate airborne testing of the ALAN camera.

1. Overall and Daily Objectives

Overall objectives were testing of an ALAN camera and stabilizing the balloon. Daily objectives are shown in Table 2 below.

Mon 12 Nov	ALAN camera set up and balloon payload preparation.
Tue 13 Nov	Daytime testing of ALAN camera.
Wed 14 Nov	Nighttime testing of ALAN camera.
Thu 15 Nov	Nighttime testing of ALAN camera.
Fri 16 Nov	Nighttime testing of ALAN camera.
Sat 17 Nov	Pack out.

Table 2. Daily Objectives for FEX I

2. Time Blocks, Personnel and Equipment Required for Testing ALAN

a. Personnel Required

Three people were required for operating the balloon and two people for helping with the test and to collect data.

b. *Equipment Required*

- Pelican Case: Axis 243 video encoder/web server, serial interface lens controller, switch, ALAN camera, environmental housing, light meter, and a laser range finder.
- Shared equipment: a laptop for testing and recording video, military field batteries, a balloon, a payload frame, network components, and handheld radios for communication.

c. *Timelines for Testing the ALAN Camera in FEX I*

In order to provide different light conditions, several tests were planned to get the benefit from different moon illuminations during weeknights. Accordingly, timelines were adjusted according to sunset times on planned test days.

Mon 12 Nov	ALAN camera set up and balloon payload preparation.
Tue 13 Nov	0800-1200: Payload set-up and operational test. 1200: Testing of video quality and link at different altitudes. 1700: Balloon recovery.
Wed 14 Nov	1630-1730: Payload set-up and operational test. 1730: Launch balloon. 1830: Testing of video quality and link at different altitudes. 2000: Balloon recovery.
Thu 15 Nov	1630-1730: Payload set-up and operational test. 1730: Launch balloon. 1830: Testing of video quality and link at different altitudes. 2000: Balloon recovery.
Fri 16 Nov	1630-1730: Payload set-up and operational test. 1730: Launch balloon. 1830: Testing of video quality and link at different altitudes. 2000: Balloon recovery.
Sat 17 Nov	Equipment pack out

Table 3. Timelines for Testing the ALAN Camera at FEX I

3. Measures of Effectiveness / Measures of Performance

a. *Measures of Effectiveness for FEX I*

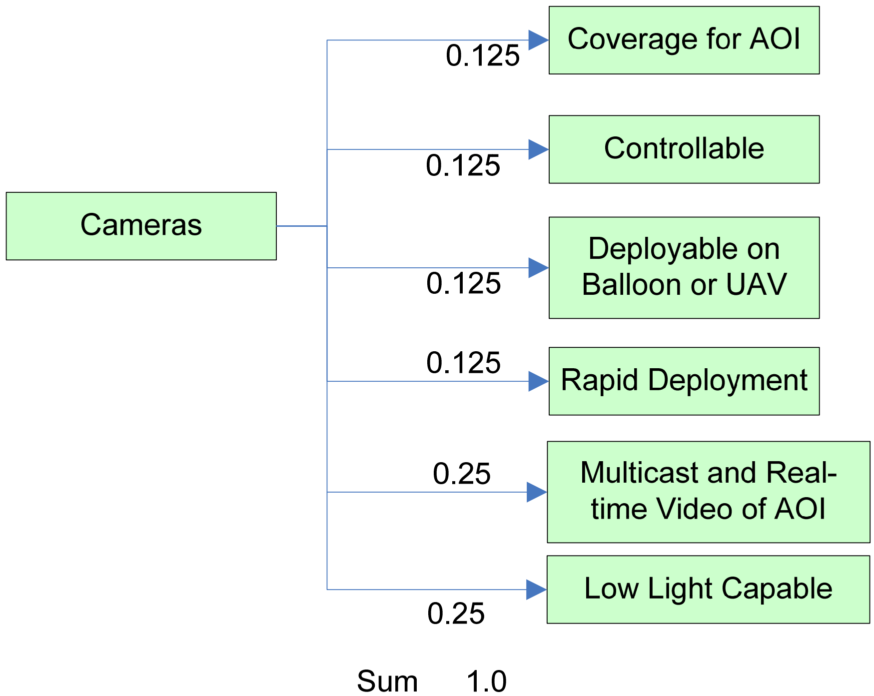

Figure 50. MOE for ALAN Camera Testing at FEX I

b. *Measures of Performance for FEX I*

Need/Want	Specification
N	Wireless connectivity
N	Control pan/tilt/zoom
N	Low light capability under 1 millilux
N	Real-time video display
W	MPEG format
W	Deployable in 10 minutes x
W	Easy configuration, minimal training required
N	Endurance time >7 days
N	Lightweight, small size
N	Operate in adverse climatic conditions

Figure 51. MOP for ALAN Camera Testing at FEXI

4. Variables

Independent	Altitude, light level, the size of the object
Dependent	Quality of link and video, coverage, detection of units

Table 4. Variables for Testing ALAN Camera at FEX I

5. Data Required From Other COASTS Members

Altitude of the balloon is required from RAPIDS team.

6. Matrix for Data Collection

Altitude	Time	Light level	Coverage	Video quality	Link quality	Detection of people	Detection of vehicle	Deployment time	Endurance time
500’									
1000’									
1500’									
2000’									
2500’									

Temperature (^{o} F)	Pressure (inHg)	Humidity (%)	Visibility

Table 5. Matrix for Data Collection in FEX I

H. TESTING AT FEX I

The first aerial night test was planned at Camp Roberts during FEX I. Unfortunately, the Federal Aviation Administration (FAA) did not permit any launches of the balloon during the exercise period, and as such the aerial testing couldn’t be executed. Instead of an aerial testing, a limited ground nighttime test was executed. The ground nighttime testing could be done for the purpose of determining the operational low-light threshold of the ALAN camera.

The ground nighttime testing was conducted in several steps. The first step was configuring and setting up the needed equipment. The Axis video server and serial interface lens controller were configured and connected to the ALAN camera. They were also contained in an environmental housing that had an Ethernet switch with ports to the outside such that the laptop was able to get video from the ALAN camera. After powering up the configuration, operational testing of the configuration was done using a laptop in order to check if video feed is available. Since no problems were experienced, the ALAN camera and the environment housing was transported to the location where ground testing could be done using portable power generators. When everything was ready, the video of the ALAN camera was recorded. A person was ready to be the test object and that person began to walk away with a light meter and a radio in the direction that the ALAN camera was pointing towards. Connecting to the serial lens controller via HyperTerminal, the tester controlled both the zoom and focus feature on the ALAN camera. Due to being required to type in commands, control of the zoom and focus feature of ALAN camera was not user friendly. The person supporting the test as the test object continued to walk until he could not be discriminated in the video of the ALAN camera. The light level was measured using the light meter by the person in the test area and relayed to the tester via radio. The process was repeated until enough measurements were recorded. In addition, the values of temperature, pressure and humidity were also recorded. The following figures show the images taken from the recorded videos during the night testing while experiencing a quarter moon and light levels ranging from 12 millilux to 25 millilux.

Figure 52. A Snapshot of the Test Video with a 25 Millilux Light Level

Figure 53. A Snapshot of the Test Video with a 25 Millilux Light Level

Figure 54. A Snapshot of the Test Video with a 20 Millilux Light Level

Figure 55. A Snapshot of the Test Video with a 20 Millilux Light Level

Figure 56. A Snapshot of the Test Video with a 12 Millilux Light Level

Figure 57. A Snapshot of the Test Video with a 12 Millilux Light Level

I. FEX II TEST PLAN

The planned COASTS scenario during FEX II was to be executed during daytime only, therefore separate airborne testing of ALAN camera was planned.

1. Overall and Daily Objectives

Overall objectives were testing of an ALAN camera and stabilizing the balloon. Daily objectives are shown in Table 6 below.

Mon 14 Jan	ALAN camera set up and balloon payload preparation.
Tue 15 Jan	Daytime testing of ALAN camera.
Wed 16 Jan	Nighttime testing of ALAN camera.
Thu 17 Jan	Nighttime testing of ALAN camera.
Fri 18 Jan	Back up day for testing of ALAN camera.

Table 6. Daily Objectives for FEX II

2. Time Blocks, Personnel and Equipment Required for Testing ALAN

a. *Personnel Required*

Same as described in FEX I above.

b. *Equipment Required*

Same as described in FEX I above.

c. *Timelines for Testing the ALAN Camera at FEX II*

Mon 14 Jan	ALAN camera set up and balloon payload preparation.
Tue 15 Jan	0800-1200: Payload set-up and operational test. 1200: Testing of video quality, link at different altitudes. 1700: Balloon recovery.
Wed 16 Jan	1630-1730: Payload set-up and operational test. 1730: Launch balloon. 1830: Testing of video quality, link at different altitudes. 2015: Balloon recovery.
Thu 17 Jan	1630-1730: Payload set-up and operational test. 1730: Launch balloon. 1830: Testing of video quality, link at different altitudes. 2015: Balloon recovery.
Fri 18 Jan	0800-1200: Payload set-up and operational test. 1200: Testing of video quality, link at different altitudes. 1700: Balloon recovery.

Table 7. Timelines for Testing the ALAN Camera at FEX II

3. Measures of Effectiveness / Measures of Performance

a. Measures of Effectiveness for FEX II

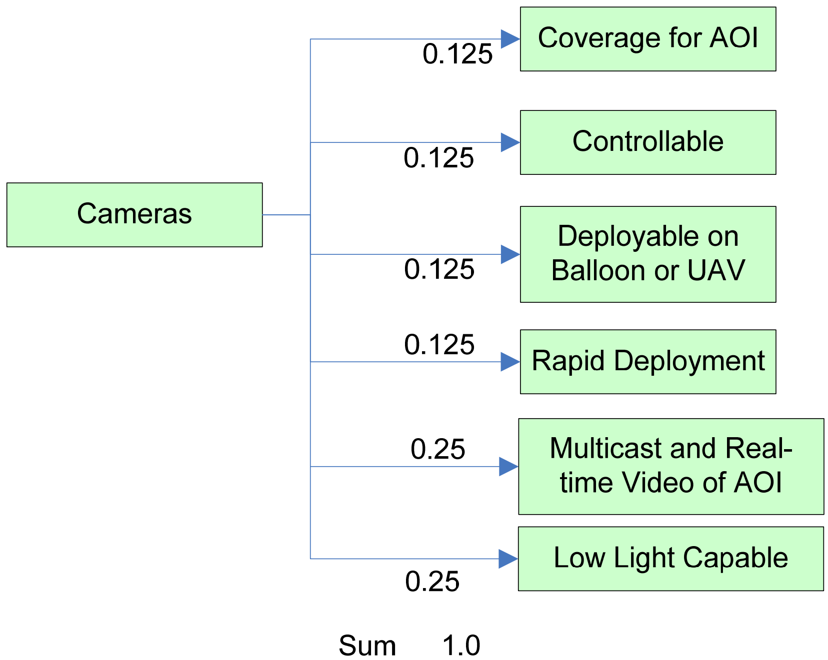

Figure 58. MOE for ALAN Camera Testing at FEX II

b. Measures of Performance for FEX II

Need/Want	Specification
N	Wireless connectivity
N	Control pan/tilt/zoom
N	Low light capability under 1 millilux
N	Real-time video display
W	MPEG format
W	Deployable in 10 minutes x
W	Easy configuration, minimal training required
N	Endurance time >7 days
N	Lightweight, small size
N	Operate in adverse climatic conditions

Figure 59. MOP for ALAN Camera Testing at FEX II

4. Variables

Independent	Altitude, light level, the size of the object
Dependent	Quality of link and video, coverage, detection of units

Table 8. Variables for Testing the ALAN Camera at FEX II

5. Data Required From Other COASTS Members

Altitude of the balloon is required from the COASTS team.

6. Matrix for Data Collection

Altitude	Time	Light level	Coverage	Video quality	Link quality	Detection of people	Detection of vehicle	Deployment time	Endurance time
500’									
1000’									
1500’									
2000’									
2500’									

Temperature (^{o} F)	Pressure (inHg)	Humidity (%)	Visibility

Table 9. Matrix for Data Collection at FEX II

J. TESTING AT FEX II

A second aerial test was planned at Camp Roberts during FEX II but pre-exercise requirements were not completed in time to allow nighttime testing. In this case, a partial ground nighttime test was executed instead of an aerial test.

The ground testing was conducted in several steps and in exactly the same manner as described above during FEX I. The following figures show the images taken from the recorded videos during the night testing. The light levels during the night test were ranging from 9 millilux to 11 millilux.

Figure 60. A Snapshot of the Test Video with a 11 Millilux Light Level

Figure 61. A Snapshot of the Test Video with a 10 Millilux Light Level

Figure 62. A Snapshot of the Test Video with a 9 Millilux Light Level

Figure 63. A Snapshot of the Test Video with a 9 Millilux Light Level at 1300’

Figure 64. A Snapshot of the Test Video with a 12 Millilux Light Level at 1300’

Figure 65. A Snapshot of the General View From the Test Video with a 12 Millilux Light Level

K. RESULTS

Since a broad aerial test of the ALAN camera couldn't be conducted for the purpose of operational testing and evaluation, the results discussed below provide an operational assessment.

The testers faced some limitations and problems during the entire testing period. The test limitations and problems impacted on the ability to formulate conclusions regarding Measures of Effectiveness and Measures of Performance. Not conducting proper prior planning to execute aerial nighttime tests resulted in the most significant limitation. Due to limited time and testing opportunities, this failure could not be overcome during both FEX I and FEX II. In addition, a lack of testing in an extremely hot environment could not be completed. Although the ALAN camera was used during numerous Thailand scenarios, the author did not capture data when it was exposed to direct sunlight. Another limitation was the lack of software available for automatic analysis of video. Software can be a valuable tool to make video analysis and object discrimination easier.

The ground nighttime tests helped determine the low light capability of the ALAN camera. According to the tests, 20 millilux serves as an operational threshold level for ALAN camera applications. Low light capability around 20 millilux does not guarantee that the system will distinguish an intruder in extremely low-light conditions at night. Since MOP requires low light capability under 1 millilux, the ALAN camera could not meet the selected MOE and MOP regarding low light tests. This shows that the ALAN camera cannot provide accurate color video when only having new moon or less amount of light in the environment. As a minimum the lunar phase of quarter moon is required to have 20 millilux light level in the environment. For example, figure 57 at 12 millilux shows a lot of graininess, where as figures 60 to 65 show much less, at even less ambient lighting conditions. Possible explanations are: (1) the presence of some ambient light in the area in Figure 57 may be reflected off subjects or surrounding and reducing the iris opening under automatic operation, despite the low millilux level of 12. Figure 57 shows a white band on the bottom of the shot, which will skew the overall light exposure to a lower Iris setting as the camera controller is interpreting an overall brighter screen in automatic mode, (2) the millilux levels in figures 60 to 65 are lower (9 to 11 millilux) but the pictures are clearer. However, these shots are taken away from any ambient light source that might be entering the iris. In this case, the camera controller is interpreting an overall darker screen and will fully open the iris, resulting in a lower light performance level. A follow up study using manual iris versus automatic iris control can clarify whether this is taking place. This seems the most likely cause of the resolution discrepancy, and the results should reflect that the camera should be operated in manual mode where great differences in exposure are present in low light, and finally (3) the lens employed can have an effect here. The 50mm ALAN lens maintains its wide 1.0 F/stop well into its zoom range whereas the 200mm ALAN lens constricts from f 1.2 to approximately f 2.5 as maximum zoom is approached. We know the 200mm lens was used for all tests. The high grainy shot in figure 57 shows an individual occupying about 25% of the frame when measured vertically. The highest zoom runway shot shows the individual at only about 1/8 or 12.5% of the frame height. This represents 1/2 the magnification of the grainy shot in Figure 57, though there is no distance data to normalize the actual magnification. The grainer shot may be at full zoom and higher f/stop in which case less light is entering the lens, and hence a grainier picture. This is also a possibility.

The relatively light runway in figures 60 to 65 reflects moonlight and starlight better than the gravel and grass in Figure 57. This would be of greater benefit for the urban surveillance mission where concrete and asphalt are present. This more even, and in effect, greater lighting may produce greater resolution at measured light levels. It should be noted that the millilux meter was a flat device blocked on one side and would measure light prominently from the overhead source rather than reflected from below. This could be examined in a follow up test by rotating the millilux meter across four positions (up, down and pointing to each side) and averaging the results.

Conversely, ALAN camera provided clear, constant, high-resolution surveillance video image to the TOC during the daytime scenarios during both FEXs.

Figure 66. A Snapshot of The Surveillance Video During The Scenarios

Furthermore, the result was also supported by COASTS-07 Technology and Operational Assessment Final Report. During Thailand scenarios, the ALAN camera was used to provide surveillance and coverage of a reservoir, and when a target vessel was sighted, the pan, tilt and zoom functions operated as required to track, identify and classify the target, as well as monitor activity on board the vessel. It is considered that the camera would be ideal for protection in an urban or military base environment where there is some surrounding ambient light. Although, the report assessed that the ALAN camera could be viable in supporting military maritime and coastal operations during day and night conditions, it was not considered to be the perfect choice under extremely low lighting conditions.

Large size and heaviness was another significant problem for airborne testing and for UAV and balloon deployment. To deploy an ALAN configuration on a balloon the other supporting equipment, such as MicroHard Radio Modems, must be selected to minimize. On the contrary, an ALAN camera may only be feasible for UAV deployment when having a small size lightweight enclosure. Thus, an ALAN camera could not meet the selected MOE and MOP concerning lightweight, small size and deployability on UAV and balloon. However, the controllability of the ALAN camera was satisfying during ground tests. The pan, tilt and zoom ability of the ALAN camera performed satisfactorily during tests. The operability of the ALAN camera configuration in adverse climatic conditions is undecided because of not being tested under very high temperatures. Additionally the supporting equipment required for the configuration of the system needs to be tested in very high-temperature environments.

Figure 67. Kestrel ALAN Camera Operating From the COASTS-07 TOC

Different equipment inclusion makes rapid deployment not feasible. Since the system configured is a design for testing, not an evolved end product, the deployment of the configuration takes a large amount time including the balloon deployment time for aerial surveillance. If it could be deployed on UAV, the time would be shorter compared to balloon deployment.

Moreover, configuration of the system for aerial testing was not easy. To provide controllability, compatibility and operability across the network, the system consisted of several essential components. Configuring all of these equipments made it hard for the testers. In contrast, minimal training was enough to operate only the ALAN camera configuration. One limitation was that no documentation existed for ALAN camera operation, including a user manual.

Wireless connectivity was feasible using additional equipment. The only constraint was weight and size of the wireless equipment to be used. Both multicast and real time video feed were satisfied with additional equipment. Using an Axis 243SA Video Server made multicast possible and enabled real time video feeds. The MPEG format was also a performance requirement, and it was satisfied by using the Axis 243SA Video Server as well.

The whole configuration was dependent on batteries. This made the system undesirable for long lasting ISR mission. There is no way to provide power to the deployed system for more than several hours. Therefore, related MOP could not be satisfied using military type field batteries as a power source.

Finally, despite the lack of measurement against every MOE and MOP the system appeared to be operationally effective and suitable when employed in its intended environment such as force protection, urban surveillance, and biometric data gathering.

VI. CONCLUSION AND RECOMMENDATIONS

Having a reliable, rapidly deployable and fully low light capable ISR system is very important for supplying real-time information to the commanders and the decision makers and also for securing the countries' borders and ports.

This thesis focused on low-light sensors including ALAN camera and their specialties in terms of providing real-time surveillance information. First, recent ISR technologies were mentioned and their applications and the current platforms were examined briefly. Then, thermal and electro-optical video cameras were examined and their applications were considered. Lastly, ALAN camera specifications and associated performance under low-light conditions were examined and tested.

In the low light level spectrum, standard CCDs or technologies such as thermal or CMOS are producing monochrome images with higher noise or with lack of detail negatively impacting ease of human depth perception [33]. Nevertheless, according to the tests executed during COASTS field experiments, the ALAN camera produced full motion full color images far down into low light intensity levels around 20 millilux where other technologies encounter performance barriers.

Furthermore, color and motion capability of the ALAN camera can be processed by a video analysis system and this can help operators interpret the locations of objects in wide-angle. This kind of information can be a valuable tool where as much personal detail as possible provides for better real time response such as in urban counter terrorism, counter narcotics, challenged biometrics and force protection. Additionally the ALAN camera can provide improved capabilities for both rapid deployment and harsh environments.

Also, it was expected that the ALAN camera could be viable in supporting military maritime and coastal operations during day and night conditions. During Thailand scenarios, it was used to provide surveillance and coverage of the reservoir, and when a target vessel was sighted, the zoom, pan and tilt functions operated as required to track, identify and classify the target, as well as monitor activity on board the vessels.

Based on the above performance the camera would be ideal for protection in an urban or military base environment where there is some surrounding ambient light, and that it would also be useful for biometrics when the lighting conditions are less than ideal such as at an airport immigration station [12]. Although, COASTS-07 Technology and Operational Assessment Final Report assessed that ALAN camera could be viable in supporting military maritime and coastal operations during day and night conditions, it was not considered to be the perfect choice under extremely low lighting conditions. Enhancing the true all light performance of the ALAN camera may be possible by coupling it with an IR illuminator for operation in extremely low light conditions.

Taking the data gathered in this research into account, it may be reasonable to assess the possibility of taking the lower operational limit of the ALAN camera to 10 milliux as seen in figures 60 to 65. We conclude the limit of the ALAN camera's lower performance envelope to be somewhat less than 10 millilux when one considers photos figures 60 to 65. It should be noted that to achieve the lower operational limit, exposure may need to be manually controlled and the characteristics of the lens may require only using as little as 50 to 80 percent of maximum zoom. The 10 milliux level is closer to a new moon on a clear night as opposed to a quarter moon. These results may be couched as conditional and the 20 percent limit taken as a general rule.

Being fully ruggedized in a sealed case is certainly an advantage of ALAN camera. This makes it ready for operational use for different environmental conditions.

In spite of the previous considerations, there is a trade-off related to optical scanning sensors as you go from short-range ground-based surveillance platforms to aerial and space-based platforms. When a long-range sensor is used, the result is lower resolution contrary to a shorter-range sensor which provides higher resolution. Besides range, there are other trade-offs resulting from the different technologies that are being used. In this instance, the limitations imposed by atmospheric conditions become more important since the sensors discussed, in general, can’t penetrate very dense smoke or clouds. Despite this, the sensors examined by this author still produce very reliable solutions in most cases because of providing high-resolution images in comparison to radar and thermal imaging solutions. However, infrared imaging can introduce two advantages. In most cases where night vision is needed, IR is used. Its thermal characteristics allow you to measure temperature variation as well as to conduct night-surveillance. It is also a good solution for detecting people even if they are camouflaged and hiding behind various obstacles. Using temperature effects, it becomes easier to detect people. This functionality makes IR systems viable for border surveillance.

In addition to these well-known systems, new combinations of systems are being introduced including the combination of lasers with other imaging systems. These new systems are being developed with the objective of providing high-resolution images and target identification. The combination of laser with other imaging systems is considered a very good balance between sensitivity and range.

High-altitude mobile observation platforms provide long-range mobile surveillance from the sky by using planes, helicopters, and satellites. With the help of their high-altitude flight capabilities, wide-area surveillance is made possible. These long-range platforms employ a mix of EO sensors enabling optical and thermal imaging, and radar for all-weather surveillance [7].

All of the surveillance platforms mentioned in the thesis can be integrated into a multi-tier surveillance system. In order for such a system to function properly, some form of aggregation must be used to process data streaming from the array of sensors in order to tie all of the data together through a security management or a C2 system. For smaller security systems, a desktop security management system would be sufficient. This computer station could also be networked to a larger, dedicated control center that monitors, analyzes and responds to the signals relayed to it from the sensors across a wide-area network, using signal analysis algorithms to process and assess the data on a central server while graphically presenting that data on display screens.

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